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Technology Review

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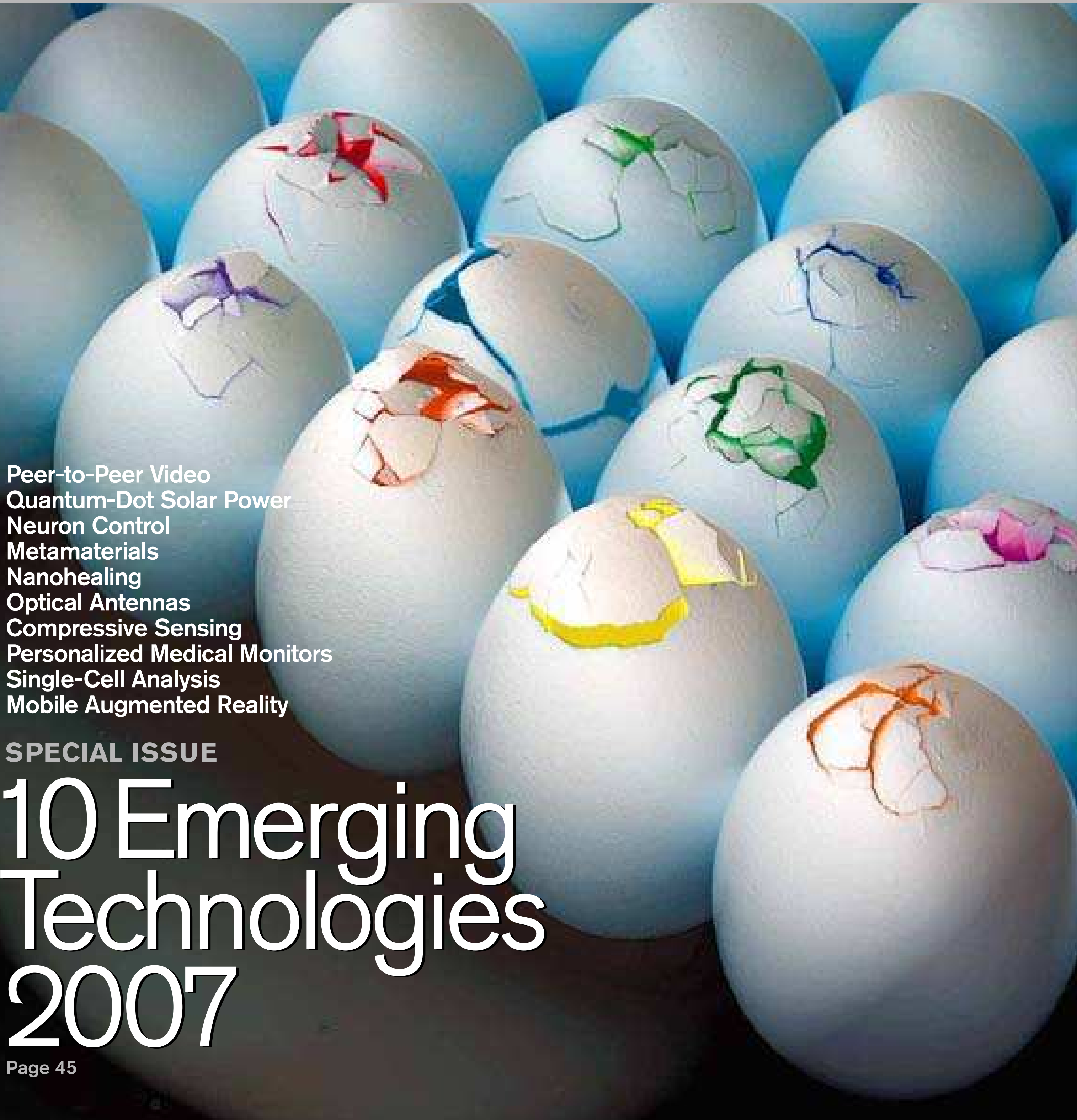

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De Technologia non multum scimus. Scimus autem, quid nobis placeat.

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What's New on Our Website

New Bloggers

In February, we introduced blogs by Simson Garfinkel and David Ewing Duncan. Here's a brief description of who these writers are and what they'll be up to on our site.

Simson Garfinkel is a fellow at Harvard University's Center for Research on Computation and Society and a researcher in the field of computer forensics. Despite having a PhD in computer science, Simson tends to be interested in the more mundane aspects of Internet life: balancing his checkbook with Quicken, reading his e-mail with IMAP, and keeping all of his data properly backed up. Simson will be writing about what makes computers fun.

David Ewing Duncan is a best-selling author, journalist, and NPR commentator. His blog will explore discoveries in the life sciences but will also offer thoughts on and analysis of how the field influences business, politics, and society. David is currently chief correspondent on NPR's "BioTech Nation" and is a regular contributor to *Technology Review*, *National Geographic*, *Wired*, *Discover*, and *Fortune*. His six books have been published in 19 languages; the latest is *Masterminds: Genius, DNA, and the Quest to Rewrite Life*.

More Videos

Be sure to watch our latest video, which offers an inside look at Alinea, a restaurant in Chicago that doesn't

so much cook food as engineer it. The restaurant and its chef, Grant Achatz, were featured in an essay by *Atlantic Monthly* food writer Corby Kummer in the January/February issue of the magazine ("The Alchemist"). Interviews with both writer and chef reveal a neat irony: sometimes technology is best used in the service of great artistic passion.

Aggregation

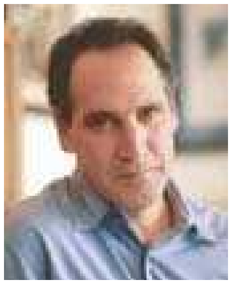
Every day our editors will comb the Web to put together "TR's Take on the Day," offering you a daily selection of the most important news and blogs.

Contributors

When **John Borland** took on the tough assignment of writing about Web 3.0, a catchall term for an elusive phenomenon, he did it fully aware of its pitfalls *("A Smarter Web," p. 64)*. "I've always been skeptical of giving any progress on the Web at large a version number," he says, "even the now well-established 'Web 2.0.' It's a catchy meme, but the analogy to software quickly raises problems. That said, there is a developing group of technologies here that does deserve a family name, even if it doesn't end up being Web 3.0. These tools are immature but hold enormous potential and may ultimately help deliver on some of the most ambitious promises we've been hearing from Web optimists for years." Borland has written about technology, science, and digital entertainment for 10 years, most recently for CNET News.com.

David Marusek obliged our interest in putting something different into this issue: fiction *("Osama Phone Home," p. 72)*. And he did so by using our content as a point of departure: "In the March/April 2006 issue of this magazine," he says, "Mark Williams wrote an article on bioterrorism that contained a line that set my science fiction imagination on fire: 'We live in a world where gene-sequencing equipment bought secondhand on eBay and unregulated biological material delivered in a FedEx package provide the means to create biological weapons.' I wondered what a homegrown, highly technological group of Western ideologues might look like. And what kind of trouble they might cook up." Marusek, the author of the novel *Counting Heads*, has published stories in *Playboy*, *Nature*, and *Asimov's*, and his work has been excerpted in *Scientific American*. His collection of stories, *Getting to Know You*, will be published in April 2007 by Subterranean Press. He is currently working on his second novel, *Mind over Oship*.

Apoorva Mandavilli wrote a review of a product she was afraid to try: a night cream whose manufacturer claims it contains "150 nano complexes" *("Nanocosmetics: Buyer Beware," p. 84)*. As Mandavilli explains, "I had no idea companies were using nanotechnology for cosmetics. There are all kinds of products out there throwing out terms like nanosomes, nano-emulsions, nano filters. The thing that I found really scary, though, is that the companies themselves seem to have no idea what these things are and how they might affect people's health. And there's no regulation. They can use anything they want in cosmetics and nobody can do anything about it. At least until something goes horribly wrong." Mandavilli is senior news editor of *Nature Medicine*. For the past few years, she has been traveling the world chasing down stories about medicine and public health, with a particular concentration on neglected communities. She maintains a blog and writes for publications such as *Nature*, *Discover*, *Women's Health*, and *O, the Oprah Magazine*.



In our roundup of 10 technologies we think likely to prove important, **Jon Cohen** reports on the ability to view, in previously unattainable detail, the contents and behavior of individual cells *("Scrutinizing Single Cells," p. 62)*. Cohen looked at the research being done by Norman Dovichi, an analytical chemist at the University of Washington, Seattle, and says that getting a peek at the instruments being built to probe cells was an amazing experience. "The lab attempts to analyze the contents of single cells, and you can see the fiber-optic 'capillaries' that hold the samples, the high-voltage electrode that zaps them, the blue and green laser lights that then shine through the 'analytes,' and the Erector Set–like platform everything sits on. Not exactly erotica, but it is sexy stuff." Cohen, a longtime contributor to this magazine, is a correspondent for *Science* and has written for the *Atlantic Monthly*, the *New Yorker*, the *New York Times Magazine*, *Slate*, and many other publications. He is the author of *Shots in the Dark: The Wayward Search for an AIDS Vaccine* and *Coming to Term: Uncovering the Truth about Miscarriage*.

Charles Simonyi and Programming

In your otherwise excellent coverage of Charles Simonyi and his pioneering concept of intentional programming ("Anything You Can Do, I Can Do Meta," January/February 2007), you unfortunately included a throwaway remark about the Unified Modeling Language (UML): "But UML diagrams can't be transformed into finished software, which is Simonyi's dream for intentional programming."

This would come as quite a surprise to a large and growing community of software architects and developers. While it is true that UML, now a staple of every major software-development tool worldwide, is often used only for "sketching" an architecture or design, people have for years been successfully employing the full capabilities of UML "all the way down" to executing systems.

Richard Mark Soley
Needham, MA

Intentional programming might be a great help to those who must maintain software, as original "intent" is often lost. However, I suspect there may be too many potential dimensions to the task. One can only hope the effort won't run off the rails. As I wrote in the March 1990 issue of *C Users Journal*, "Complexity is neither created or destroyed—it only changes its appearance or location and distribution."

Scott Maley
Condon, OR

I found the criticism of the intentional-software idea referred to in the article amusing to ludicrous. The notion that Simonyi's idea is "implausible" is astounding. It reminds me of the prediction of scientists that the four-minute mile was a human physiological barrier. Every single scientific breakthrough has received that sort of dismissal before it was achieved.

Also, the complaint from programmers that it distances them from the "raw code" is ludicrous. Being stuck with the raw code is exactly the problem that intentional software is aiming to solve. The complaint sounds like a concern over job security.

Richard Odessey
Lawrenceville, GA

Charles Simonyi's intentional programming is a great idea, but Simonyi's huge programming background unfortunately ties him so much to conventional programming techniques that, no matter how hard he tries, he will never be able to conceive of the truly radical approach to programming that's needed to solve the software crisis. We need someone not steeped in

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current programming methods to devise a totally new, unfettered approach. I wish Simonyi the best of luck in his endeavor, but I fear we're only going to get a marginal reduction in program obfuscation and a still further slowdown in run-time speed. Let's hope it's not a C+++.

Bill Earle
Scituate, MA

I liked editor in chief Jason Pontin's most recent column about programming languages ("On Rules"), but I am a little bit disappointed that he did not mention Prolog, a rule-based software language model that is really elegant in terms of expressing solutions to problems. Once upon a time, I used a mixture of Prolog and C, and I can tell you it was a real delight. On the other hand, I remember an article in *Technology Review* by the late Michael Dertouzos about making all computing matters simpler ["Creating the People's Computer," April 1997]. I do not see that spirit in Simonyi's proposal. What I think is more in line with Mr. Dertouzos's agenda is what is known as Business Process Management (BPM) systems. Most BPM solutions offer a Lego-like graphical programming paradigm that allows the user to define his organization's processes and computations. I think this is the paradigm we should follow.

Luis Fernando Flores Oviedo
Aguascalientes, Aguascalientes, Mexico

Uninspiring Vista

It's a shame that writer Erika Jonietz has only now discovered that "Macs are simple" ("Uninspiring Vista," January/February 2007). I discovered this in 1984, when they first came out.

Many people in the academic and business communities still wonder why this discovery has been, and continues to be, so elusive and rare. I turned on my first Mac, opened Macword, and was working productively in five minutes. That has been my standard ever since. Around 1991, one could put together a LAN with Macs and printers just by plugging wires together. On a PC system, it took full-time administrative personnel to set up and keep such a system running. In 1991 and 1992 I worked in two different offices with networked PC systems, and no one at either place could tell me how to print in landscape format from Lotus 1-2-3. I had to print in portrait format, cut out and tape the pieces together, and put them on a copy machine to get the format I needed. No such antics were ever needed on a Mac.

Daniel Whitney
Cambridge, MA

Correction: In the January/February 2007 essay "The Alchemist," we inaccurately described the Institute of Food Technologists, which is a scientific society made up of 22,000 members working in academia, government, and the food industry.

From the Editor

On Science Fiction

How it influences the imaginations of technologists

I once wrote on this page, "Science fiction is to technology as romance novels are to marriage: a form of propaganda" *(see "Against Transcendence," February 2005)*.

This represents my sincere view, but stated so baldly, without elaboration, the remark implies a contempt I do not feel. For I *adore* science fiction. If it is propaganda, I am its happy dupe; and if I am a technology editor and journalist today, it is because between the ages of seven and fourteen, I read little *but* science fiction.

I grew up on a farm on the North Coast of California that had at one time been a kind of hippie commune. Around the various cabins on the property were dozens of yellowed paperbacks of the sort that the counterculture loved; and when I recall my childhood all at once, it is perpetually summer, and I am alone in a field or a tree house, reading Alfred Bester, Algis Budrys, Samuel R. Delany, Philip K. Dick, or Robert Heinlein.

I grew out of science fiction—which is to say that I learned to enjoy other, more literary writing and to disguise my passionate fandom. But science fiction continues to influence me. To this day, my tastes and choices as an editor and journalist are bluntly science fictional: I look for technologies that are in themselves ingenious and that have the potential to change our established ways of doing things. Best of all, I like technologies that expand our sense of what it might mean to be human.

In this, I believe, I am an entirely conventional technologist. Most of us came to technology through science fiction; our imaginations remain secretly moved by science-fictional ideas. Only the very exalted are honest about their debt. In his collection of lectures on the future of technology, *Imagined Worlds*, the great theoretical physicist Freeman Dyson writes, "Science is my territory, but science fiction is the landscape of my dreams."

Science fiction's influence on technologists' imaginations can be observed in its successful and unsuccessful predictions. Discerning a causal relationship between what science fiction has predicted and what technologists have created might be an instance of the logical fallacy *post hoc ergo propter hoc* ("after this, therefore because of this"), except for a curious fact: SF writers not only describe current research and extrapolate its likely development but also prescribe cool things that enthralled technologists later make or try to make. In short, life imitates art.

Fans decry any emphasis on their favored genre's predictive power (science fiction, they say, is really about the present day); but nonetheless, the accurate predictions of many science fiction writers are justly famous. Geostationary telecommunications satellites were first proposed by Arthur C. Clarke in a paper titled "Extra-Terrestrial Relays: Can Rocket Stations Give World-Wide Radio Coverage?" published in *Wireless World* in October 1945. Space travel has been a staple of science fiction since Jules Verne published *De la Terre à la Lune* in 1865. Robots first appeared in Karel Čapek's play *R.U.R.* in 1921. Indeed, it is more useful to ask, What *hasn't* SF predicted?

But the prescriptive power of science fiction has functioned both positively and negatively. Older computer scientists and electrical engineers such as Marvin Minsky and Seymour Cray, born in the mid-1920s, pursued a vision of humanlike artificial intelligence and mainframe computing popularized by science fiction after World War II (see Isaac Asimov's "Multivac" stories). These scientists remained committed to the glamour of big computing long after research suggested that it would not soon produce the thinking machine for which they pined. Here, science fiction's predictions were wrong, but still influential.

By contrast, consider the influence of science fiction on the development of the personal computer and the Internet. It is often said that SF missed both, but that isn't really true. The "cyberpunks" and their precursors began dreaming of the Net in the late 1970s. Algis Budrys's highly literate 1977 novel, *Michaelmas*, describes a worldwide web of telecommunications and computer data. Vernor Vinge, in 1981's *True Names*, anticipated a cyberspace that is recognizably our own. Most notably, William Gibson invented the "consensual hallucination" of the Matrix in *Neuromancer*, published in 1984. These fictions were greatly influential on younger technologists, such as Tim Berners-Lee and Jaron Lanier. The Web would not be the demotic, freewheeling society it is without the cyberpunks.

One can go further. In his survey of science fiction, *The Dreams Our Stuff Is Made Of: How Science Fiction Conquered the World*, Thomas M. Disch writes, "It is my contention that some of the most remarkable features of the present historical moment have their roots in a way of thinking that we have learned from science fiction." I think he's right, and so we're publishing some science fiction of our own: a story by David Marusek, author of the acclaimed 2005 novel *Counting Heads* (*see "Osama Phone Home," p. 72*). Write and tell me what you think at jason.pontin@technologyreview.com. **Jason Pontin**

MARK OSTOW

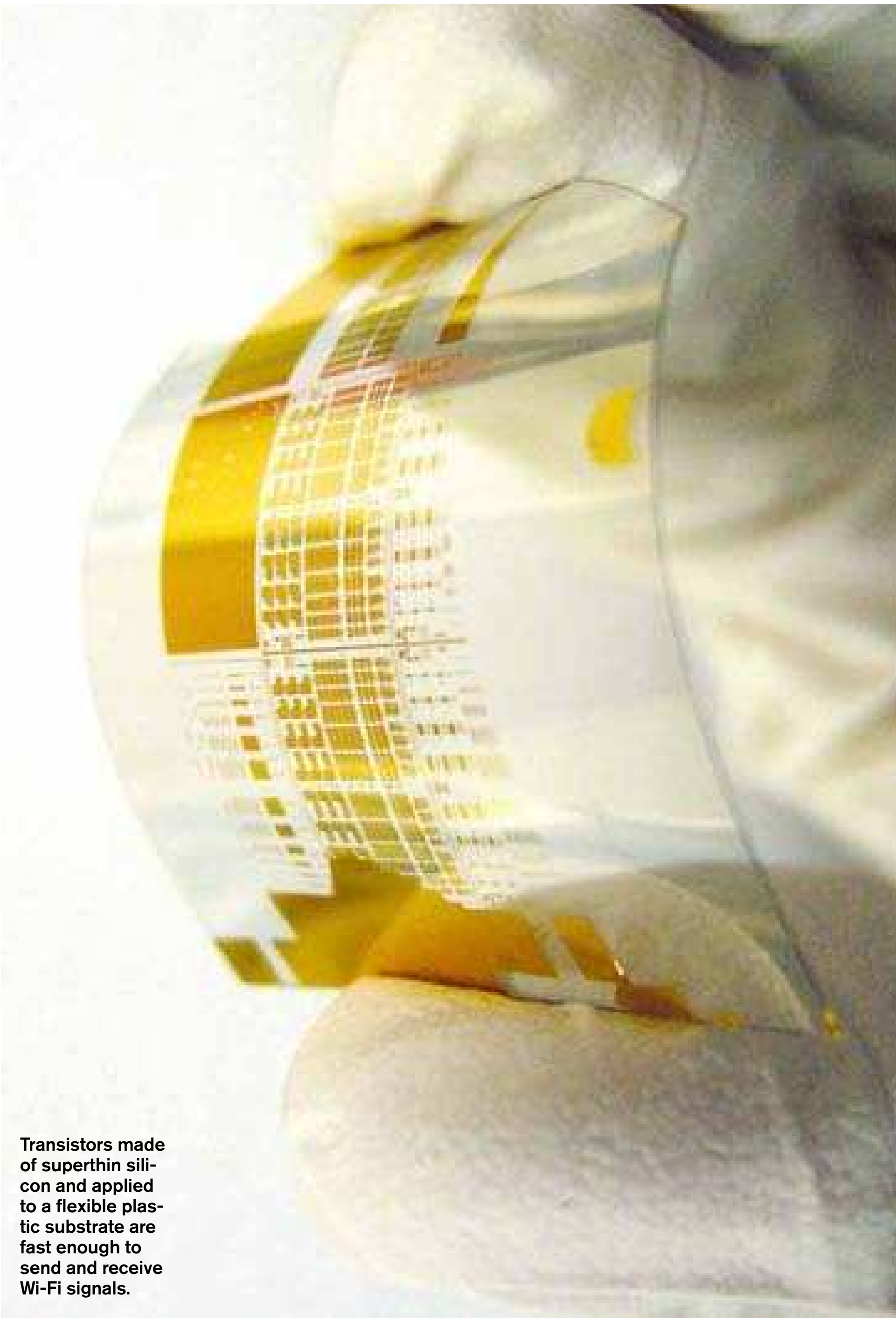
Forward

HARDWARE

Fast, Bendable Computers

Already, flexible-but-slow polymer electronics have made their way into technologies like roll-up digital displays. If superfast silicon electronics could also be made flexible, we might be able to do things like weave computing devices into clothing, or mold antennas around an airplane's fuselage, making for more precise radar. Now researchers at the University of Wisconsin–Madison have made ultrathin silicon transistors that are 50 times as fast as their predecessors.

Previously, researchers at the University of Illinois at Urbana-Champaign showed that nanometer-thin films of single-crystal silicon transistors could be made flexible. But Wisconsin researchers Zhenqiang Ma, professor of electrical and computer engineering, and Max Lagally, professor of materials science and physics, improved the transistors' performance by putting strain on the silicon's crystalline structure, increasing electron mobility. And by altering fabrication methods to reduce electrical resistance, Ma achieved a transistor speed of 7.8 gigahertz—fast enough for, say, a flexible sensor that could send and receive Wi-Fi signals. Ma says he expects to reach speeds of 20 gigahertz; military antennas are a likely first application. **Kate Greene**



Transistors made of superthin silicon and applied to a flexible plastic substrate are fast enough to send and receive Wi-Fi signals.

ZHENQIANG MA, UNIVERSITY OF WISCONSIN–MADISON

SECURITY

Detecting Suicide Bombers

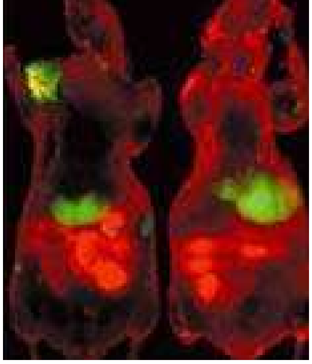
Screening people for bombs doesn't do much good if a suicide bomber simply pulls the trigger at the checkpoint. A new technology could detect bombs by directing a low-power radar beam at people from a safe distance—as far as 100 meters away. Signal-processing software reveals concealed objects without producing an under-the-clothes image that could violate privacy. The technology, developed by SET of Arlington, VA, is assisted by video analysis software designed by Rama Chellappa, a professor of electrical and computer engineering at the University of Maryland. Chellappa's software tracks the movements of the person being screened, which helps keep the radar on target. The software could one day augment the technology even further by discerning subtle differences in the way people walk when they're concealing heavy objects. Thomas Burns, CEO of SET, says the device, dubbed CounterBomber, could be ready for sale by this fall. —*Karen Nitkin*

Analysis of video and radar data from this device reveals bombs under clothing.

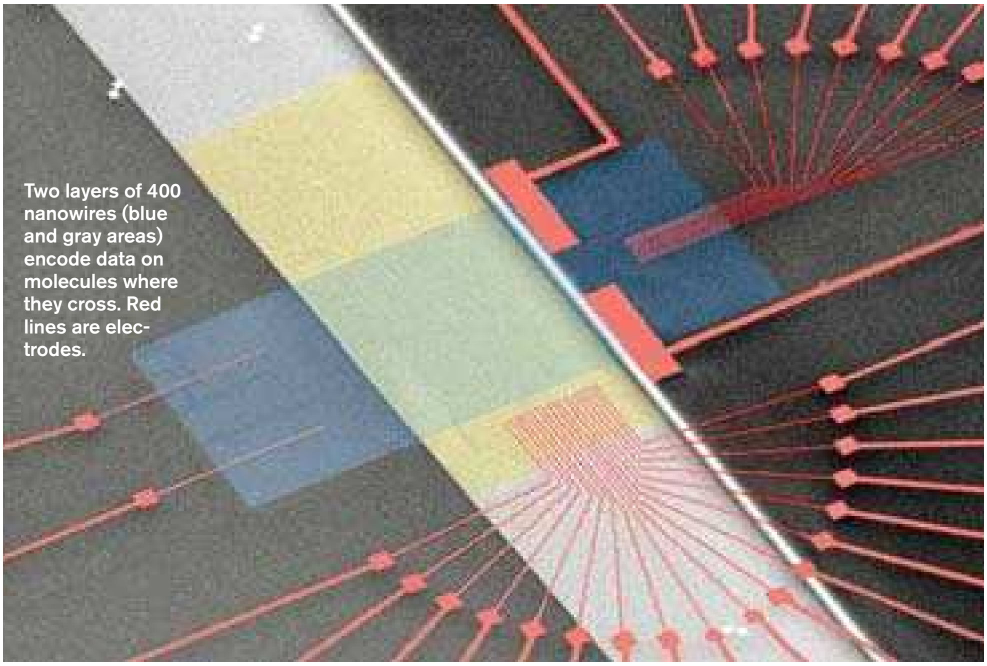
NANOTECH

Tumor-Killing Nanoparticles

A new class of nanoparticles that accumulate inside tumors could one day improve imaging quality and cancer treatment by delivering image-enhancing agents or cancer drugs directly to tumor sites. A team led by Erkki Ruoslahti, a professor at the Burnham Institute for Medical Research in La Jolla, CA, coated iron oxide nanoparticles with a peptide that is attracted to protein clots in tumor blood vessels. When injected into mice with breast cancer, the nanoparticles sought out the tumors and bound to their blood-vessel walls. For reasons the researchers do not yet understand, the particles also induced more clotting, which attracted more particles, enhancing their effectiveness and potentially choking off a tumor's lifeblood. The team is working to ensure that the particles won't build up in normal tissues. —*Prachi Patel-Predd*



Fluorescent peptides attached to iron oxide particles glow bright green in a tumor (top left) and in the liver in these images of mice.



Two layers of 400 nanowires (blue and gray areas) encode data on molecules where they cross. Red lines are electrodes.

NANOTECH

Nano Memory

Researchers at Caltech and the University of California, Los Angeles, have reached a new milestone in the effort to use individual molecules to store data, an approach that could dramatically shrink electronic circuitry. One hundred times as dense as today's memory chips, the Caltech device is the largest-ever array of memory bits made of molecular switches, with 160,000 bits in all. In the device, information is stored in molecules called rotaxanes, each of which has two components. One is barbell shaped; the other is a ring of atoms that moves between two stations on the bar when a voltage is applied. Two perpendicular layers of 400 nanowires deliver the voltage, reading or writing information. It's a big step forward from earlier prototype arrays of just a few thousand bits. "We thought that if we weren't able to make something at this scale, people would say that this is just an academic exercise," says James Heath, professor of chemistry at Caltech and one of the project's researchers. He cautions, however, that "there are problems still. We're not talking about technology that you would expect to come out tomorrow." **Kevin Bullis**

PNAS (TUMOR); JONATHAN E. GREEN AND HABIB AHMAD (NANO); COURTESY OF SET CORPORATION (BOMB)

Using as many fingers as they like on large touch screens, researchers at New York University drag, drop, crop, and resize images.

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HARDWARE

Wall-Size Touch Screens

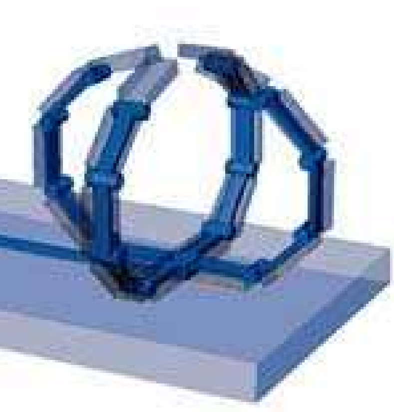
Multi-touch displays advance

The iPhone may be getting lots of attention, but Steve Jobs has no corner on "multi-touch" displays, which allow a person to use multiple fingers to do things like zoom in and out of pictures. At New York University's Courant Institute of Mathematical Sciences, research scientist Jeff Han has developed an effective way to make large, very high-resolution screens that accommodate 10, 20, or even more fingers. Applications could include interactive white boards, touch-screen tables, and digital walls.

In Han's setup, a digital projector shines an image on a six-millimeter-thick clear acrylic screen. Touch sensitivity comes from infrared light-emitting diodes attached to the edges of the screen. Normally, the diodes' light reflects internally and stays trapped within the acrylic. Once fingers or other objects touch the acrylic, though, the light diffuses at the point of contact and scatters outside the surface. A camera behind the screen detects these changes. Simple image-processing software can interpret the scattering, in real time, as discrete touches and strokes.

"The new iPhone is too small to be a very interesting multi-touch device," says Han. With larger screens, multiple users could collaborate—in brainstorming sessions that use networked, interactive white boards, for instance, or animation sessions joined by many artists.

Versions of multi-touch technology have been around since the 1980s, but they never took off commercially. Multi-touch screens "never completely went away, but they're coming back in different ways," says Bill Buxton, principal researcher at Microsoft Research. Han's company, Perceptive Pixel, shipped its first wall-size screen to an undisclosed U.S. military customer this winter. **Kate Greene**



MICROMACHINES

Tiny Robotic Hand

In a UCLA School of Engineering lab, a mechanical hand only one millimeter wide plucks a single fish egg from an underwater clutch. "It is the world's smallest robotic hand and could be used to perform microsurgery," says Chang-Jin Kim, who led its development. Unlike other tiny machines of its kind, the device *(depicted above)* is flexible yet strong and is controlled by air, not electricity. The microhand has four "fingers" made of several pieces of silicon each, with polymer balloons serving as "muscles" at the joints. Each balloon is connected to narrow channels through which air is pumped. When a balloon is inflated or deflated, the angle between joints changes, making a finger contract or relax. The device is one to two years from practical use; Kim is working with a company to develop a new version, with optical fibers on the palm—a microhand with an eye—that would enable a doctor to see, allowing better control during an operation. —*Amitabh Avasthi*

IMAGING

Seeing Greenland

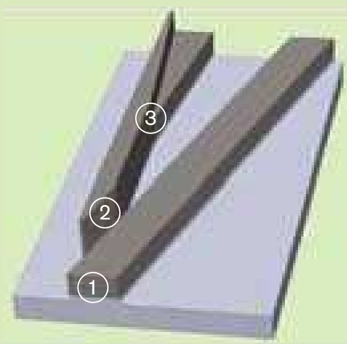
There's enough frozen water in Greenland to raise global sea levels seven meters, and enough in Antarctica to raise levels 65 meters. But the rate of melting is poorly understood, partly because ice-sheet surfaces look so inscrutably white and featureless in ordinary satellite images and to the human eye. Now, a new image-processing technique gives a clearer view of critical features of inland ice.

The technology starts with as many as 94 red and infrared images of the same region, taken by two NASA satellites, *Terra* and *Aqua*, with orbits that cross Greenland several times a day. By aligning and averaging values within areas of pixel overlap, researchers tightened resolution from 250 meters per pixel to as little as 150 meters, says Ted Scambos, the lead scientist and glaciologist at the National Snow and Ice Data Center at the University of Colorado at Boulder, who was one of the developers. The new approach also allows rapid reëvaluation of the entire ice sheet overlying Greenland to detect important short-term changes. "What we've got is a map that shows details much further inland, much better than before," says Scambos. "Other images just show the interior of the ice sheet as a blank white surface." Mark Fahnestock, a geologist at the University of New Hampshire in Durham who collaborated with Scambos, says the technology is key to understanding today's accelerating ice-sheet melting. **David Talbot**

Thanks to new image-processing technology, fine-grained features of ice flow are visible within this eyedropper-shaped 600-by-50-kilometer ice formation in Greenland.

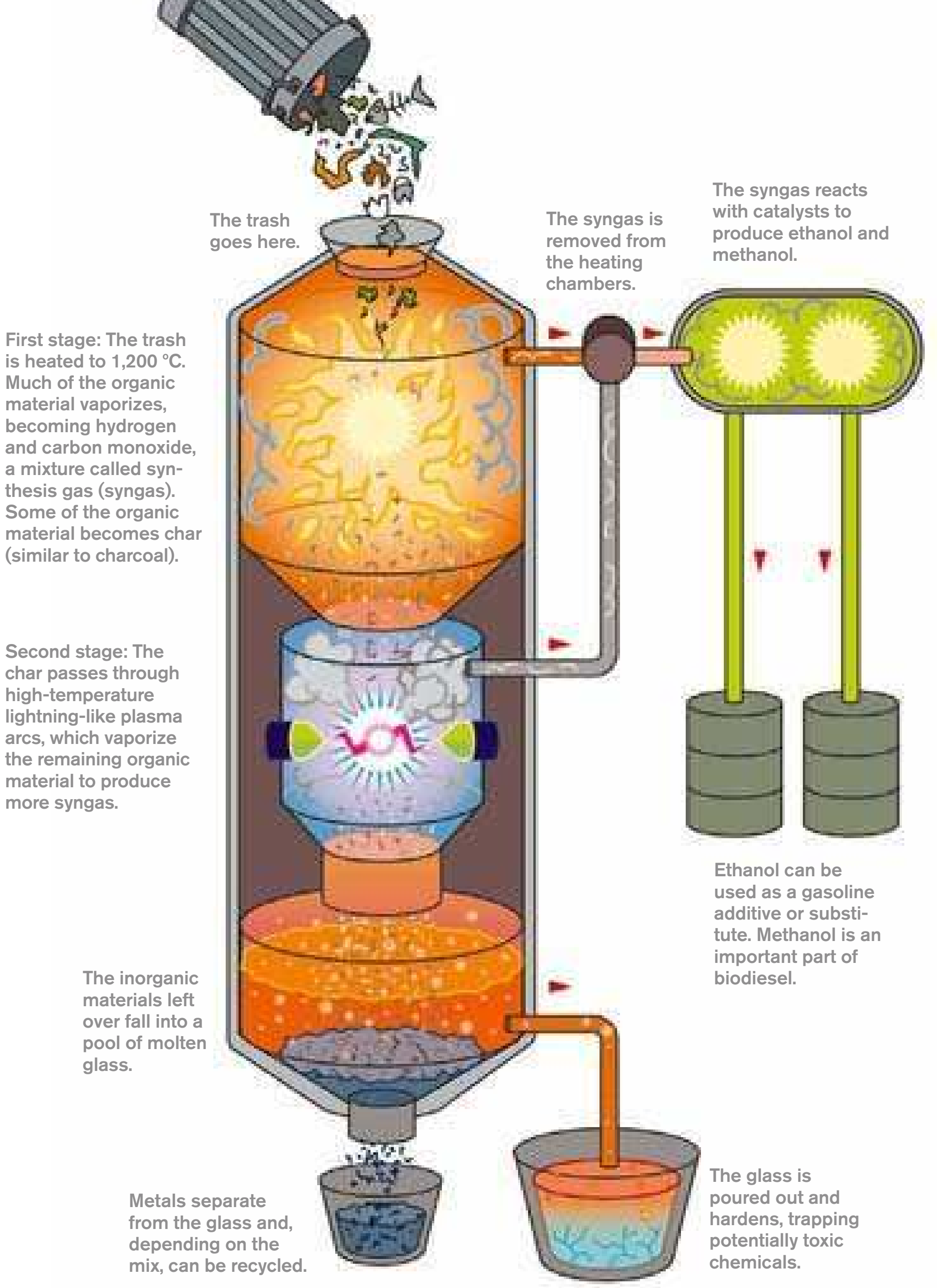
PHOTONICS

Light Twister



The data-carrying light waves in optical fibers have either horizontal or vertical polarities. Both types of waves are easily processed in today's millimeter-scale photonic devices, but polarization differences may lead to signal loss in future micrometer-scale devices on chips. This submicrometer structure from MIT's Research Laboratory of Electronics can be etched into silicon. Light enters a waveguide (1) and is split (2) into horizontal and vertical components. Vertical beams are rotated (3) to horizontal for processing and later recombined. —*Kevin Bullis*

CHANG-JIN KIM (HAND); NATIONAL SNOW AND ICE DATA CENTER, UNIVERSITY OF COLORADO AT BOULDER (GREENLAND); TYMON BARWICZ (LIGHT)



ENERGY

Garbage Power

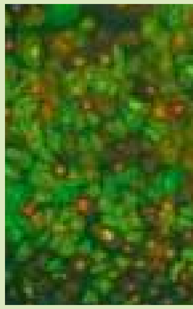
Forget corn-derived biofuels. Think garbage. The process shown above uses lightning-like arcs of plasma to transform garbage and other waste into gases from which methanol and ethanol can be made. Unlike conventional incineration, it doesn't generate toxic pollutants, and it yields up to six times as much energy as it consumes. Since its fuel—garbage—would be brought to a landfill or incinerator anyway, the technique would avoid the extra energy costs associated with growing and processing corn. The technology, based on research at MIT's Plasma Science and Fusion Center and the Pacific Northwest National Lab in Richland, WA, is now being commercialized by Integrated Environmental Technologies (IET), also in Richland. There's enough energy in U.S. municipal and other waste to replace as much as a quarter of the gasoline the country uses, says Daniel Cohn, cofounder of IET and senior research scientist at the MIT center. IET is in talks with a utility and several municipalities to construct the first such plants, says CEO Jeff Surma. **Kevin Bullis**

BIOTECH

Fake Skin Kills Bacteria

One of the problems with artificial skin is its vulnerability to infection. Synthetic skin is used in burn treatment and plastic surgery, but blood vessels, which carry the immune system's machinery, may not connect to the new dermis for a week or two. "Without blood vessels, bacteria can grow and cause infection," says Ioannis Yannas, a bioengineer and materials scientist at MIT who helped develop the first artificial-skin product, approved by the U.S. Food and Drug Administration in the mid-1990s. In a new approach, cultured skin cells are genetically modified to produce higher levels of an antibacterial protein. The cells multiply in the lab and are injected into a collagen matrix of artificial skin. "We're using genetic modification to try to get the cultured skin to behave more like normal skin," says Dorothy Supp, a researcher at the Cincinnati Shriners Hospital for Children in Ohio, who led the project. Supp cautions that the engineered cells are far from clinical use: the true test of their bacteria-fighting properties will come in the complex environment of a real wound. The researchers are planning experiments in animal models. The technique could eventually be used to make skin that can sweat and tan after implantation.

—*Emily Singer*



Skin cells engineered to produce more antibacterial proteins appear green.

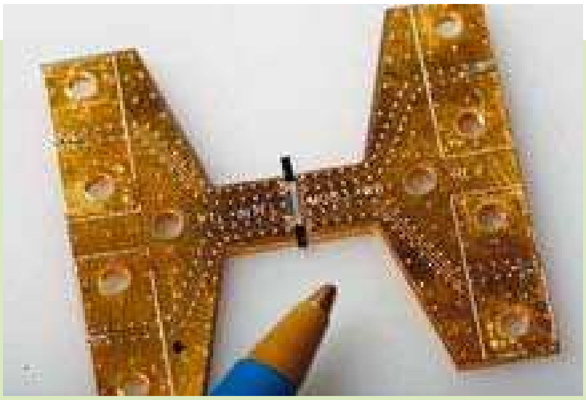
JEFF WEST (GARBAGE); UNIVERSITY OF CINCINNATI (SKIN)

The first peek at a much-hyped new battery technology will come courtesy of electric cars made by Zenn Motor of Toronto.

ENERGY

A Battery Beyond Belief?

Is EEStor of Cedar Park, TX, for real? The secretive company announced earlier this year that it plans to begin shipping a 15-kilowatt-hour electrical-energy storage system that can propel a small electric car 322 kilometers and takes just minutes to charge. The first customer: Toronto-based Zenn Motor, which makes electric vehicles. EEStor says its technology is a cross between a battery and an ultracapacitor (which quickly stores and releases energy) and is based on mysterious barium titanate powders. Company documents claim that the new storage system has better energy density than lithium-ion and nickel–metal hydride batteries, that it charges more quickly, and that it's cheaper and safer. The implications are enormous and, for many, unbelievable, but the company says it's all true. "We're well on our way to doing everything we said," says Richard Weir, EEStor's cofounder and chief executive. —*Tyler Hamilton*



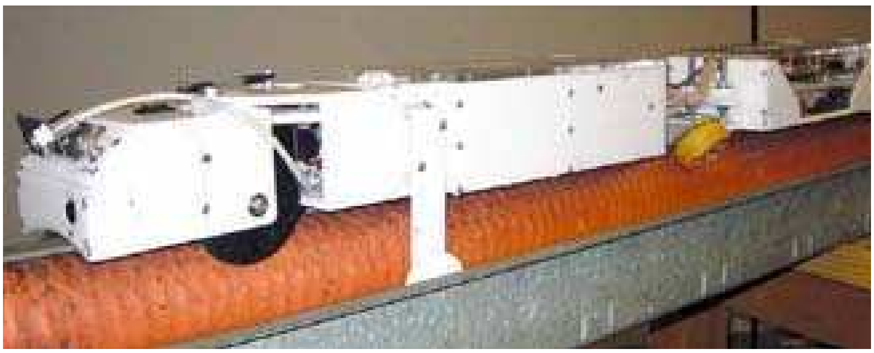
TELECOM

Superfast Silicon Optics

Historically, photonic devices, such as the modulators that encode data onto light beams, have been made of exotic materials. In 2004, however, Intel researcher Mario Paniccia and his team showed that with clever engineering, modulators and lasers could be made from silicon. Paniccia's latest invention is shown above. A modulator sits on the millimeter-wide strip of silicon at the center of the device. It has reached speeds of 30 gigabits (the equivalent of about 8,000 digital photos) per second, approaching the 40-gigabit-per-second speed of today's best modulators. Paniccia says his technology could be commercialized by 2010. He adds that 25 silicon lasers combined with "an array of 25 modulators operating at 40 gigabits per second" would yield "a terabit of information all on a piece of silicon the size of my fingernail." —*Kate Greene*

ROBOTICS

Power Bot



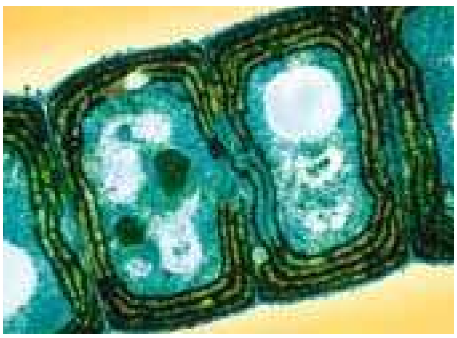
Just three inches high, this robot could help keep the power grid humming by diagnosing faulty power lines in difficult-to-access tunnels and pipes. The robot hugs underground power cables, rolling along them on small plastic wheels; it carries a thermal sensor to locate hot spots, an acoustic sensor to listen for the crackle of sparks, and a dielectric sensor to detect moisture. The battery-powered robot also has a gyroscope to help maintain its balance and stabilizing arms to right it if it slides off track. The gadget is the fruit of a project led by Alexander Mamishev, professor of electrical engineering at the University of Washington, Seattle. The technology "looks very promising," says Dave Hawkins, a project manager at the California Independent System Operator, a nonprofit organization that manages much of the state's power grid. Though the robot can access only the 10 percent of underground cables that are found in pipes or tunnels (as opposed to those buried directly in the ground), those are often the ones that suffer damage from water and other causes. The robot was recently tested in New Orleans, where it was sent underground to search for Hurricane Katrina damage. **Kate Greene**

ZENN MOTOR (BATTERY); JEFFREY TSENG (OPTICS); COURTESY OF MAMISHEV LAB (ROBOT)

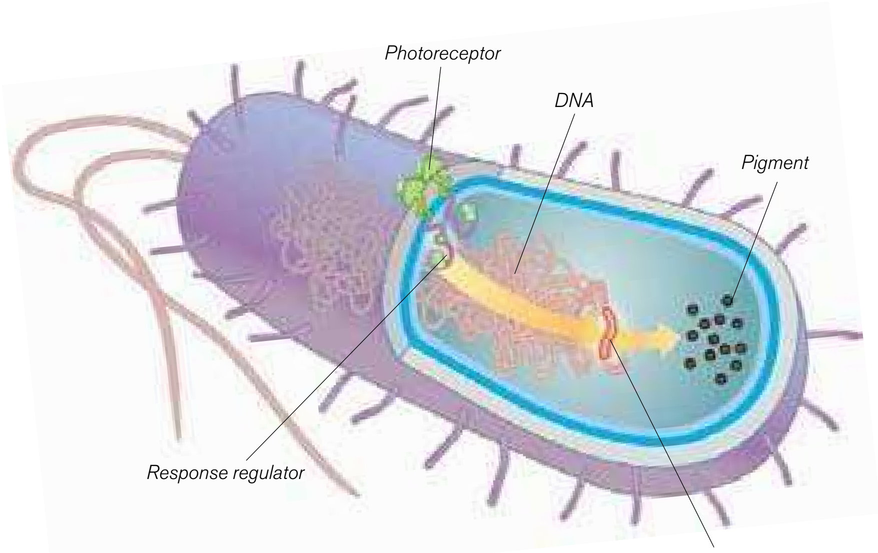
Synthetic Biology on Display

Researchers are fooling around with *E. coli*. **By Daniel Turner**

Christopher Voigt and his research partners at the University of California, San Francisco, and the University of Texas at Austin hacked the genes of *E. coli* bacteria, making each altered cell photosensitive. (Voigt is a member of the current TR35, our annual list of 35 exceptional innovators under the age of 35. He and the others were featured in the September/October 2006 issue.) Their first application of the technology, shown here, was a lawn of bacteria that acts like a photographic plate: when exposed to red light, the lawn reproduces an image inscribed into a stencil held between it and the light source. But this isn't the goal of Voigt's research—it's just an example of the powerful possibilities raised by the young field of synthetic biology. The ability to precisely engineer and control microörganisms could lead to new bacterial factories that produce complex drugs or materials.



1 Thanks to photoreceptive proteins called phytochromes, plants and some bacteria can respond to light—moving to face the sun, for example—in order to maximize photosynthesis. *E. coli*, however, has no phytochromes. Voigt and his team extracted phytochrome DNA from cyanobacteria (shown here), which, like green plants, are photosynthetic.



2 Phytochromes have two functional parts: a photoreceptor, which is a sensor that responds to light, and a response regulator, which receives a signal from the sensor and triggers further reactions inside the cell. Voigt and his team fused the photoreceptor from the cyanobacterium to molecular machinery within *E. coli* that communicates with a gene-regulating protein (see above). This created a tiny organic circuit that responds to light.

3 Once they'd genetically inserted their light sensor into the *E. coli*, Voigt and his team linked it to LacZ, an *E. coli* gene that produces a pigment under certain conditions. When the *E. coli* was exposed to light, the LacZ was suppressed and no pigment produced. In the dark, the activated LacZ gene initiated a reaction producing an insoluble, stable black precipitate—much like photographic ink. Voigt and his team now had a simple photographic mechanism: the altered *E. coli* that were not exposed to light turned dark; the *E. coli* in the light did not. The team then shone light through a stenciled image—similar to a film negative—and onto a dense lawn of the hacked *E. coli*.

LINDA NYE (*E. COLI*); JEFF TABOR (LAB); BIOPHOTO ASSOCIATES/PHOTO RESEARCHERS, INC. (CYANOBACTERIA); AARON CHEVALIER (DARWIN)

4 The amount of pigment that each cell produced corresponded to the duration of its light exposure, allowing Voigt and his team to tease out gray tones in their images. Shown here is an image of Charles Darwin.

Vinod Khosla

A veteran venture capitalist's new energy

For many years a partner at the blue-blooded venture capital firm of Kleiner Perkins Caufield and Byers, Vinod Khosla has been called the best venture capitalist in the world by both *Forbes* and *Red Herring* magazines. Certainly, he has succeeded more grandly and more reliably, and has failed less spectacularly, than any of his peers. In 2004, he founded Khosla Ventures, which advises entrepreneurs and invests in his latest area of interest: the clean energy technologies that might replace the burning of coal and oil.

***TR:* Whence this newfound preoccupation with clean energy generation?**

Khosla: I enjoy looking at hard, important problems that are still manageable.

Funding new energy technologies has been the work of governments and big businesses. Do you really think energy a good investment for VCs?

Not every energy project can be funded by venture capitalists; some have very long time lines and big budgets. But there are plenty of opportunities that are amenable to a venture approach.

Why are you skeptical about efforts to make coal-based energy generation cleaner and more efficient?

How fast do you think existing energy vendors will move to these clean coal technologies? Alternatives to coal and oil can get here much faster. That said, clean coal is one option for future power generation. We need reliable, predictable power; many people believe that coal can provide that. But concentrating solar power [CSP] is also a real option for large-scale, high-capacity, dispatchable power. Thermal underground storage of heat can be used for utility-grade power generation, too. If large-scale compressed-air energy storage [CAES] works, then wind power will become scalable. So I think there will be a horse race between clean coal with carbon sequestration, wind with CAES, and solar thermal power generation with storage. I think carbon capture and sequestration will be difficult, making clean coal more expensive than CSP. Today, I would put my money on CSP.

What are the benefits of biofuels?

Biodiesel is a good product, but it's nonscalable unless it can be made from biomass instead of seed product. Ethanol is a good start, and it will transition quickly to cellulosic-based production. But I believe new fuels like butanol will come along. I would not be surprised to see biogasoline either, initially made from corn and later from biomass.

When will solar cells, or photovoltaics, be sufficiently efficient to contribute significantly to the globe's energy needs?

Don't equate solar with photovoltaic. I think CSP, leveraging the large investment in traditional, steam-based power generation, and using passive mirrors to concentrate heat, can get to 35 percent efficiency today at $500 per kilowatt. For photovoltaics to compete, we'll need multijunction thin-film solar cells produced with cheap mass-production technologies, and efficiencies above 30 percent.

Does building wind turbines using coal power vitiate their value as an alternative energy?

Many technologies today have long payback periods before the energy invested in them is returned. If it takes so much coal power to produce the solar cell or wind turbine that we are not clean-energy positive for four or five years, is that really a problem? But technology is not static, and all the newer technologies will improve, and the payback period will get faster and faster. These kinds of arguments are generally advanced by proponents of traditional energy and economists who are not used to rapid improvements in technology.

Does nuclear energy have a place in a clean-energy future? After all, France generates 75 percent of its power through nuclear energy.

Nuclear could have a future. That said, I suspect we are unlikely to go to mostly nuclear power in the U.S., because the political and regulatory risks are too high and the time line to build plants is too long. What we really need is to build a big, high-voltage DC power grid, and let nuclear, wind, solar photovoltaics, solar CSP, electricity from biomass and waste, and anything else innovators can think of get on the grid. We need to kick-start the alternatives and let the competitive ones prosper.

Do you believe in the hydrogen economy that President Bush and others have promoted?

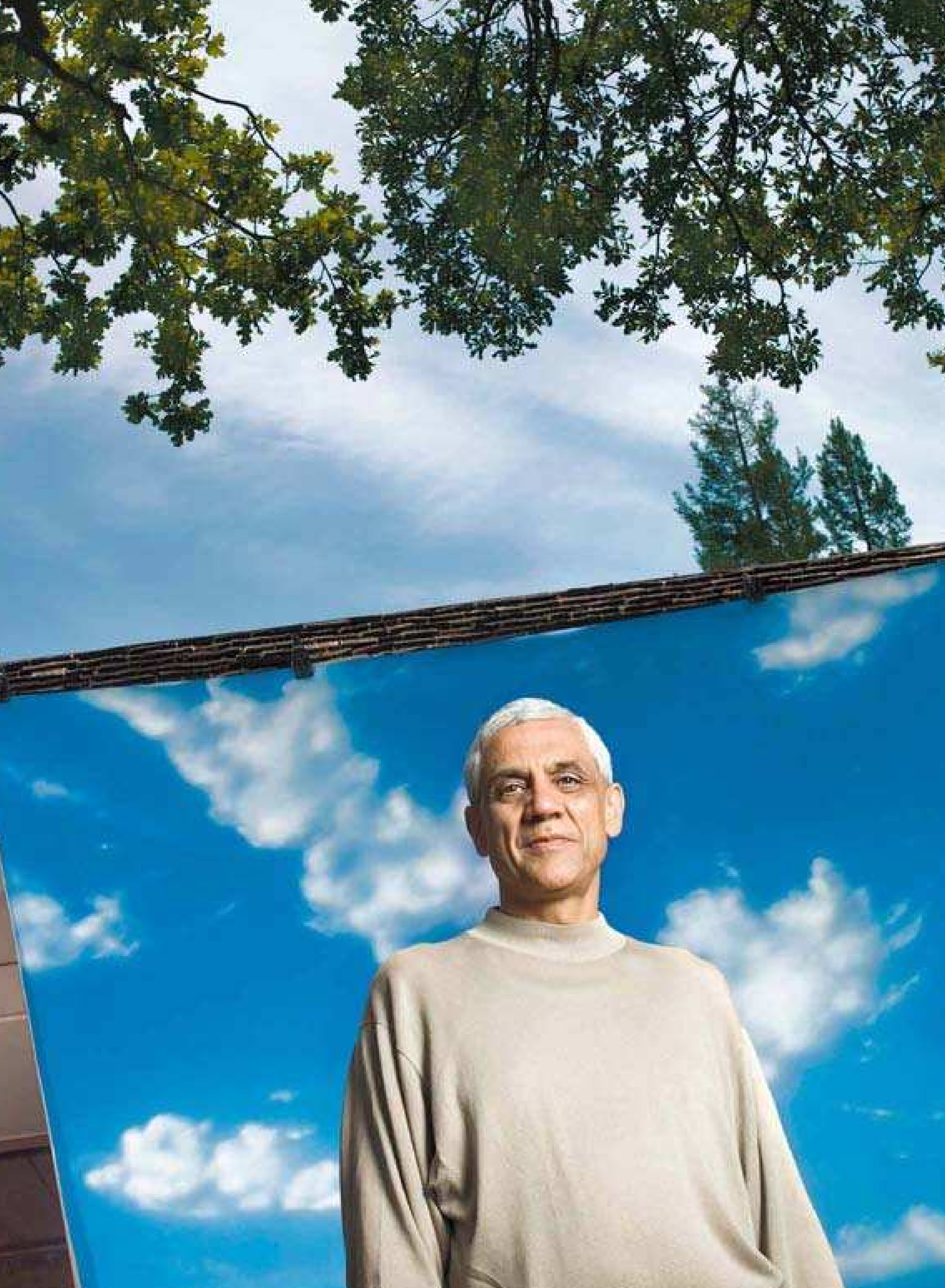
Hydrogen makes no sense to me. There are forces that like any technology that is far enough away that they don't have to make any real changes. We will want to reëvaluate hydrogen in 10 years, but it does not look like a winning option to me today.

Apart from energy, you've also shown some interest in investing in new markets for microloans. Why?

Microloans are the most effective tool in addressing poverty. I am not a big believer in the aid and development programs that big governments favor. But if entrepreneurs use microloans to make biomass an important feedstock, for instance, we will do more to address poverty than all the foreign aid from all the developed world. And biomass can be used to produce fuels, electricity, plastics, and much more.

JASON PONTIN

BART NAGEL

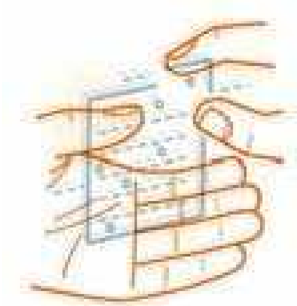


OPEN SOURCE

Open Source and You

Sun Microsystems' **Ron Goldman** says the real value of open-source software is the community it fosters.

No one would buy a car with the hood welded shut, but that is essentially what commercial software is. However, since computing began, some software has been distributed in such a way that users can change or repair it by modifying its source code—the step-by-step instructions that the computer executes when the software runs. Software distributed under a license that allows a programmer to modify the source code and freely distribute an improved version of it is called open source.



Open-source software can make good business sense. For example, a company might be able to reduce costs by building a product on top of an existing open-source application rather than writing it from scratch. But does open source matter to those who do not program computers? I think the answer is yes.

Open source is often discussed as if it were just about the code, but it's really about the community of people who care about the code, or rather, who care about the things that open-source software helps them do. Within that community, some conversations will focus on the specifics of source code, but many more are about how to best use a tool or how to improve it. The community surrounding a given piece of open-source code is a valuable resource for people who want to share tips and best practices, get help with problems they are having, and chat about their successes.

In this respect, an open-source community is similar to a conventional user group, in which consumers discuss (or complain about) a company's proprietary product. But unlike a user group, the open-source community includes the developers who are creating the next version of the product. This direct connection between those who write the software and those who apply it in their work allows developers to hear firsthand about what's good and what's bad. That feedback in turn allows open-source projects to more directly meet the needs of the software user than do similar commercial efforts where customer information is filtered by sales, marketing, and management before it reaches the developers.

In an open-source project, everyone—programmer or nonprogrammer—is involved in the design of new features. Good ideas can come from anyone in the community. Open discussion helps to refine the ideas, from their inception on through their implementation in the software. This process encourages product innovation. Just take a look at the new features being added to an open-source application like the Mozilla Firefox browser. These include the more than 2,000 extensions and almost 300 themes that have been contributed by community members.

Open source provides some hope that future software may become more robust. Commercial software is usually written under great time pressure: the need to start selling the next release is more important than fixing current bugs or adding certain features. Open-source projects tend to have a more organic approach, releasing new versions whenever there is enough new stuff to make it worthwhile, or just to fix existing bugs.

A final way in which open source has changed things is that now, for the first time, there is lots of source code publicly available for aspiring programmers to read and study. Much like writers studying literature, or architects analyzing great buildings, programmers examining source code can see examples of good design and style. Open source is transforming the end result of software development from throwaway code that is used once to code that we inhabit and modify over time to better suit our changing needs. TR

Ron Goldman is a researcher at Sun Labs and coauthor of Innovation Happens Elsewhere: Open Source as Business Strategy.

NEUROENGINEERING

Engineering the Brain

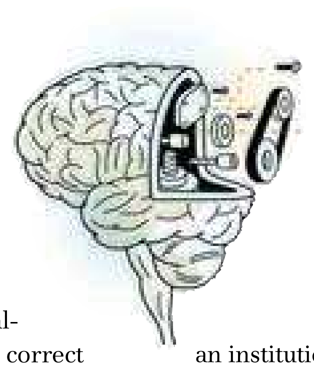
New tools, says **Edward Boyden**, are allowing neuroscientists to precisely control neurons.

The last century has seen great progress in our understanding of those aspects of neural computation that can be studied through experimentation on one or a few cells—for example, how synapses enable a neuron to talk to one of its neighbors. But the phenomena that got many neuroscientists interested in the brain in the first place—learning, emotion, consciousness, and mysterious disorders such as depression and schizophrenia—remain difficult to explain through experiments on just one or even a few cells. Thousands or millions of cells, computing as an ensemble, are responsible for practically all of our behaviors, as well as the derangements thereof.

Due to the complexity of neural circuits, the practice of systems neuroscience remains a fine art. Beyond the single neuron, computational details remain hazy for most of the neural circuits in the brain.

Before becoming a neuroscientist, I trained as a physicist and an engineer. So I decided to try to invent tools to help solve the old, unyielding problems of the normal and pathological brain. I have launched a new research group at the MIT Media Lab to develop technologies for controlling neuronal activity and to use them to find and engineer the circuit elements mediating specific states and behaviors. We will also apply these technologies to devising more-targeted and noninvasive strategies for correcting brain disorders. These efforts may enable neuroscientists to understand better the links between neural-circuit activity and conditions such as depression *(see "Neuron Control," p. 50)*.

In 2005, I was able, along with my colleagues at the Max Planck Institute of Biophysics and Stanford University, to cause specific neurons to fire spikes precisely in response to brief pulses of blue light, by expressing in the neurons a unique membrane protein from green algae *(see "Artificially Firing Neurons," September/October 2006)*. My lab is developing automated protocols for using this technique and other neural-control tools we're inventing to systematically reveal the patterns of circuit activity and behavior that are mediated by a specific neuron or set of neurons. We are also exploring the systematic use of neural-control technologies to correct neurological and psychiatric deficits and to improve cognition.



Our brains are the ultimate interface between us and the world. Directly engineering this interface may give us new insights into how we feel sensations, decide upon actions, and become aware of ourselves—and enable new modes of communication, neural prosthesis, and cognitive augmentation. The question of how we subjectively experience reality is one of the great unsolved problems of all time and will require new tools, and collaboration across disciplines, to answer. I believe that in this quest, the skills and efforts of neuroengineers will be essential. TR

Edward Boyden is an assistant professor at the MIT Media Lab, where he leads the new Neuroengineering and Neuromedia Lab.

INNOVATION

Corporate Fountain of Youth

Corporate support for innovation needs to begin at the board level, says **Sheldon Buckler**.

A deeply ingrained culture of innovation is vital for all companies, but particularly for those that are technology based; it is innovation that allows a technology company to continually generate new business. For this kind of culture to take hold, all the microcultures in a company—including those devoted to business planning, marketing, operations, and developing new ideas—must be understood, supported, and (though they may at times seem incompatible) brought together under leadership that truly cares about creativity.

When such a culture is in place and creating a steady stream of innovations, a company enjoys an institutional value beyond Wall Street appraisals based on financial metrics. In my experience serving on the boards of a variety of companies, this outcome is easiest to achieve in private companies, where management can focus on creating long-term value without fretting about a few pennies per share with every quarterly report.

Startup companies have no difficulty at all in treasuring innovation, since that is the foundation of their enterprise. But in order to keep a culture of innovation alive in established private companies, that culture must be deeply embedded in the board of directors. Its importance must be stressed when top management is selected and evaluated; it must be central when the board sets the company's goals and direction. Established companies, however, seldom use this seemingly obvious criterion in selecting their board members. Instead, board members are generally sought for their financial, legal, and other worthy skills. Innovation then typically declines, which in turn shortens corporate life spans—to less than 40 years on average.

To test my feeling about this, I asked members of two executive-search practices whether experience in and passion for innovation were often among the qualifications sought in prospective board members. Both said they recalled no request for such qualifications, although they did get requests for backgrounds in academia and technology. This response clearly suggests that those who are responsible for making board selections in established companies inadequately understand innovation and lack commitment to it.

I am convinced that all technology companies stand to gain in both vitality and longevity if they focus on bringing people who support innovation to the enterprise in many roles, but particularly at the board level. TR

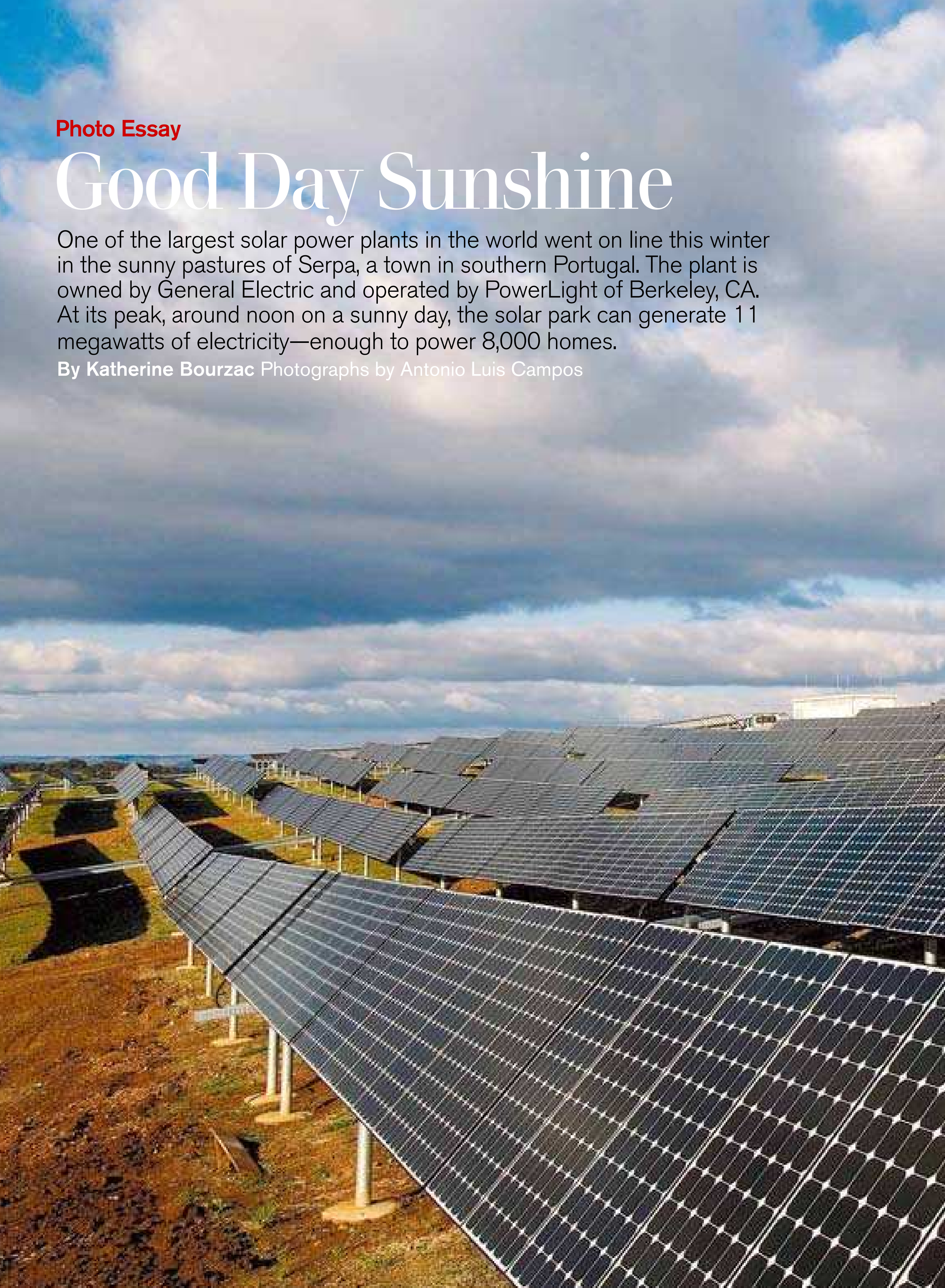
Sheldon Buckler is chairman of Lord Corporation, a private technology-based company in Cary, NC. (A minority share is owned by a foundation that exclusively benefits MIT.)

Photo Essay

Good Day Sunshine

One of the largest solar power plants in the world went on line this winter in the sunny pastures of Serpa, a town in southern Portugal. The plant is owned by General Electric and operated by PowerLight of Berkeley, CA. At its peak, around noon on a sunny day, the solar park can generate 11 megawatts of electricity—enough to power 8,000 homes.

By Katherine Bourzac Photographs by Antonio Luis Campos

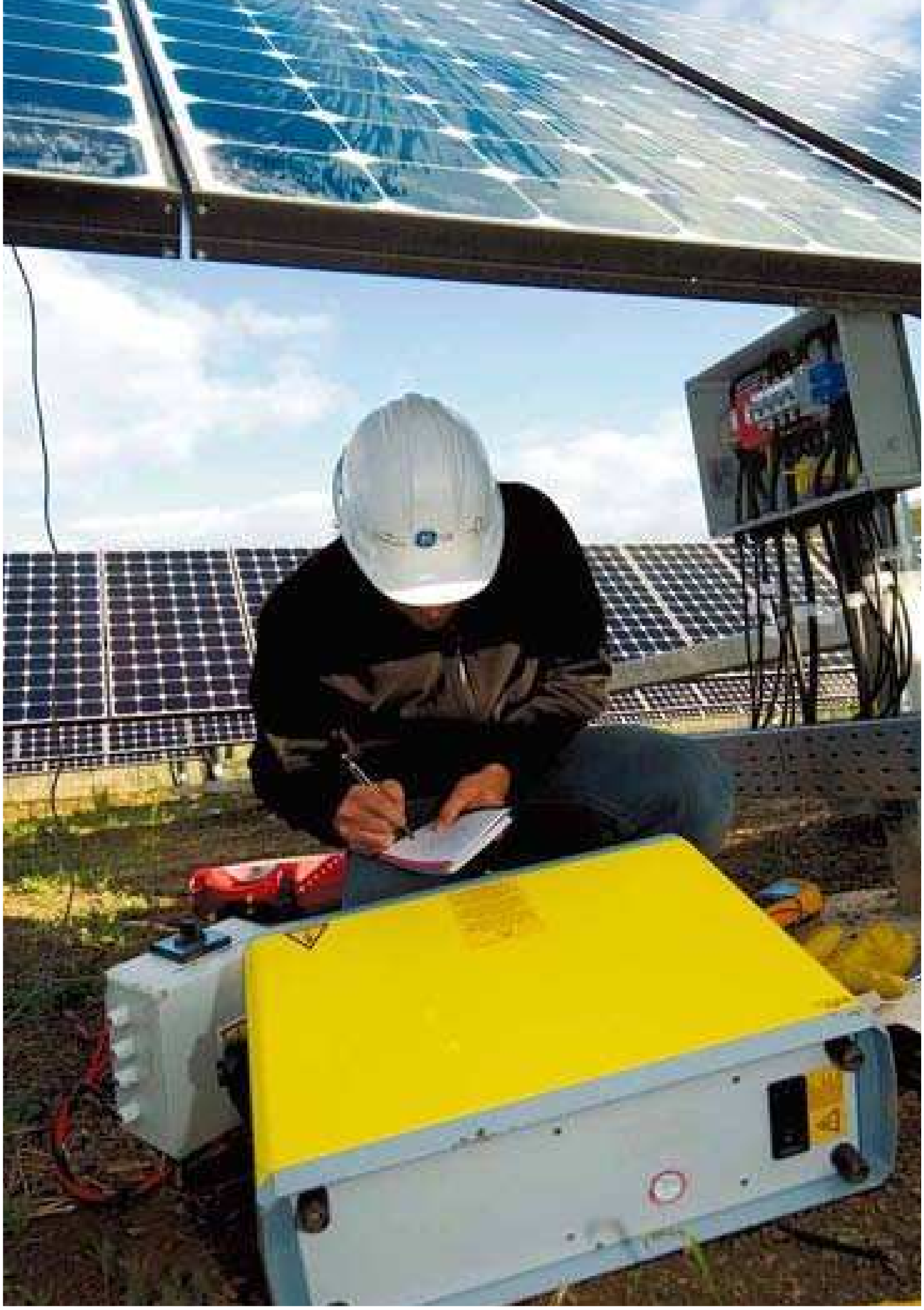


The Serpa plant's 90 acres are covered by 52,000 panels that support nearly four million solar cells (black squares, opposite page). Howard Wenger, executive vice president of PowerLight, says that building a solar park this large offers economies of scale: it is less expensive than installing the same number of solar cells in smaller plants or on the roofs of individual businesses and homes. The park cost General Electric $75 million and is expected to turn a profit. Portuguese utilities are required to purchase electricity from the plant, with a federal subsidy of a few cents per kilowatt-hour. Customers whose utilities buy solar power will see less than a tenth of a percent increase in their electric bills. Wenger expects the plant to produce 21,340 megawatt-hours of electricity each year, reducing the region's carbon dioxide emissions by 13,000 tons over the same time period.

Serpa is about as sunny as central California. But even on a stormy day, the plant is productive. Sensor stations like the one above monitor the weather and the sun's location and control the angle of groups of solar panels. PowerLight's Wenger compares the rows of panels to slats on Venetian blinds: long, motor-powered metal beams attached to the panels adjust their angle throughout the day. In the morning, the panels angle to catch the sun in the east; when the sun is at its peak they are parallel to the ground; as the sun sets, they angle toward the west.

The panels are high enough off the ground for sheep to graze underneath, and the Serpa park will double as pasture for livestock.

Photo Essay



The final stages of the solar park's construction included checking the panels' orientation with an inclinometer (below right) and testing the maximum output of the panels. The readout below is a graph of current versus voltage for a string of panels. It tells technicians like Doug Felmann (right) how much of the sunlight striking the solar cells is being converted into electricity.

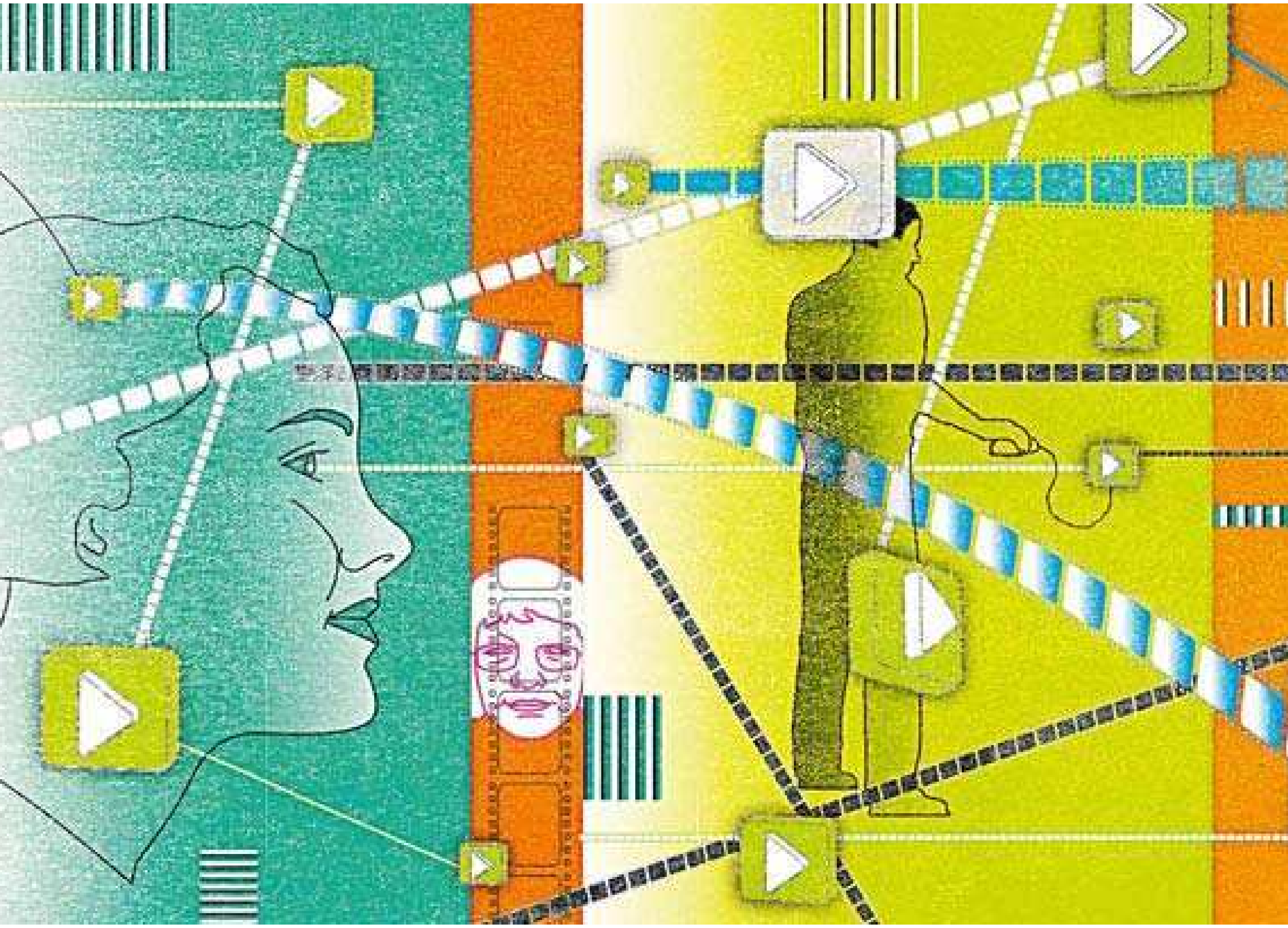
The plant is designed to operate with no staff on site. Rain will wash the panels occasionally. PowerLight and General Electric will monitor the output of groups of panels over the Internet; PowerLight will dispatch technicians as needed for repairs and once a year for preventive maintenance.

PowerLight is building an even larger plant near Las Vegas this year.

Emerging Technologies 2007

As always, *Technology Review*'s annual list of emerging technologies to watch comprises projects in a broad range of fields, including medicine, energy, and the Internet. Some, such as *optical antennas* and *metamaterials*, are fundamental technologies that promise to transform multiple areas, from computing to biology. Our reports on *peer-to-peer video*, *personalized medical monitors*, and *compressive sensing* reveal how well-designed algorithms could save the Internet, simplify and improve medical diagnoses, and revamp digital imaging systems in cameras and medical scanners. *Nanohealing* and *quantum-dot solar power* demonstrate the potential of nanotechnology to make a concrete difference in our daily lives by changing the way we treat injuries and helping solar energy deliver on its promises. Precise *neuron control* could help physicians fine-tune treatments for brain disorders such as depression and Parkinson's disease. And *single-cell analysis* could not only revolutionize our understanding of basic biological processes but lead directly to predictive tests that could help doctors treat cancers more effectively. Finally, by combining location sensors and advanced visual algorithms with cell phones, *mobile augmented reality* technology could make it easier to just figure out where we are.

DAVE BRADLEY



INTERNET

Peering into Video's Future

The Internet is about to drown in digital video. Hui Zhang thinks peer-to-peer networks could come to the rescue.

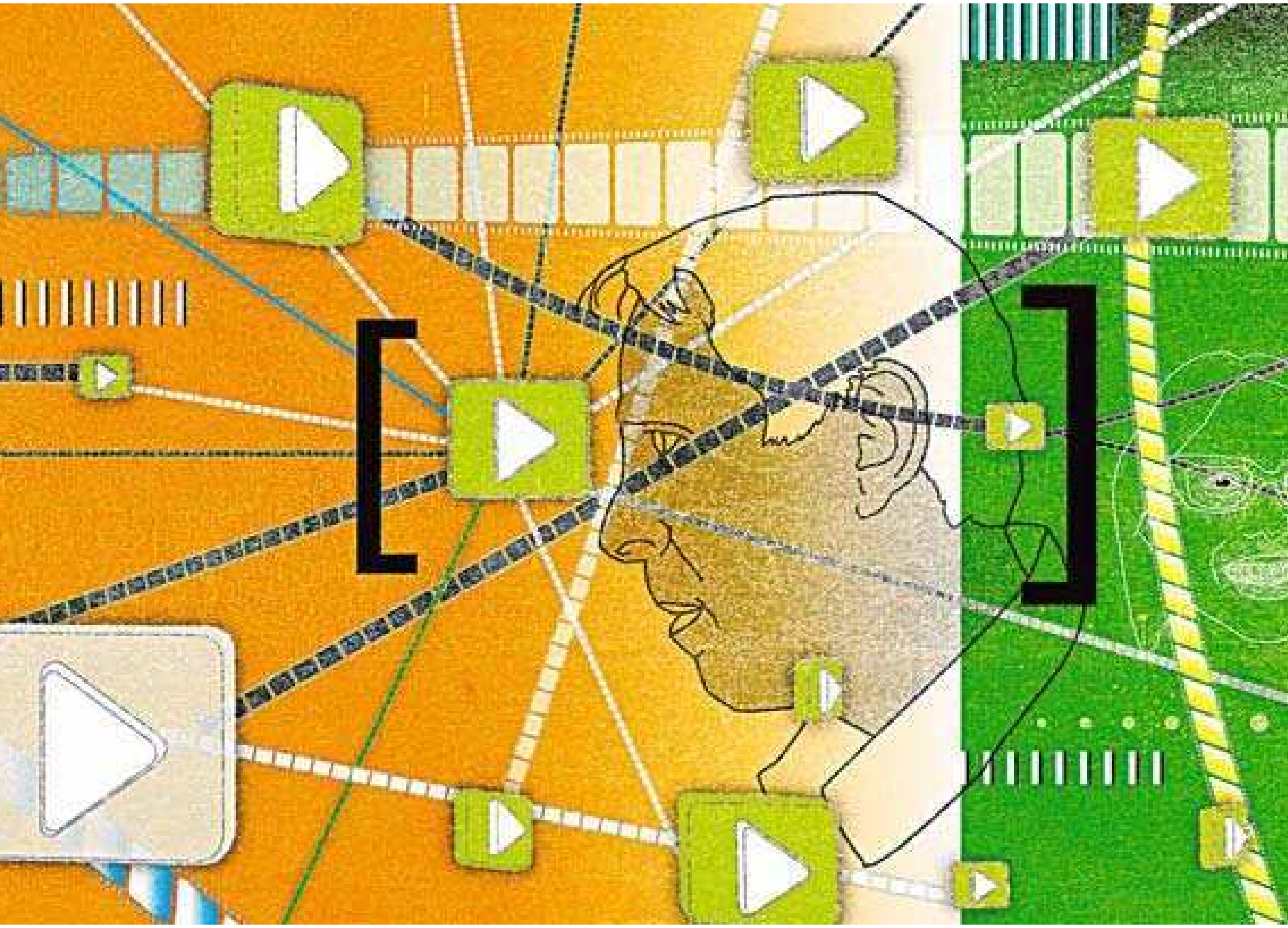
By Wade Roush

Ted Stevens, the 83-year-old senior senator from Alaska, was widely ridiculed last year for a speech in which he described the Internet as "a series of tubes." Yet clumsy as his metaphor may have been, Stevens was struggling to make a reasonable point: the tubes can get clogged. And that may happen sooner than expected, thanks to the exploding popularity of digital video.

TV shows, YouTube clips, animations, and other video applications already account for more than 60 percent of Internet traffic, says CacheLogic, a Cambridge, England, company that sells media delivery systems to content owners and Internet service providers (ISPs). "I imagine that within two years it will be 98 percent," adds Hui Zhang, a computer scientist at Carnegie Mellon University. And that will mean slower downloads for everyone.

Zhang believes help could come from an unexpected quarter: peer-to-peer (P2P) file distribution technology. Of course, there's no better playground for piracy, and millions have used P2P networks such as Gnutella, Kazaa, and BitTorrent to help themselves to copyrighted content. But Zhang thinks this black-sheep technology can be reformed and put to work helping legitimate content owners and Internet-backbone operators deliver more video without overloading the network.

JOHN HERSEY



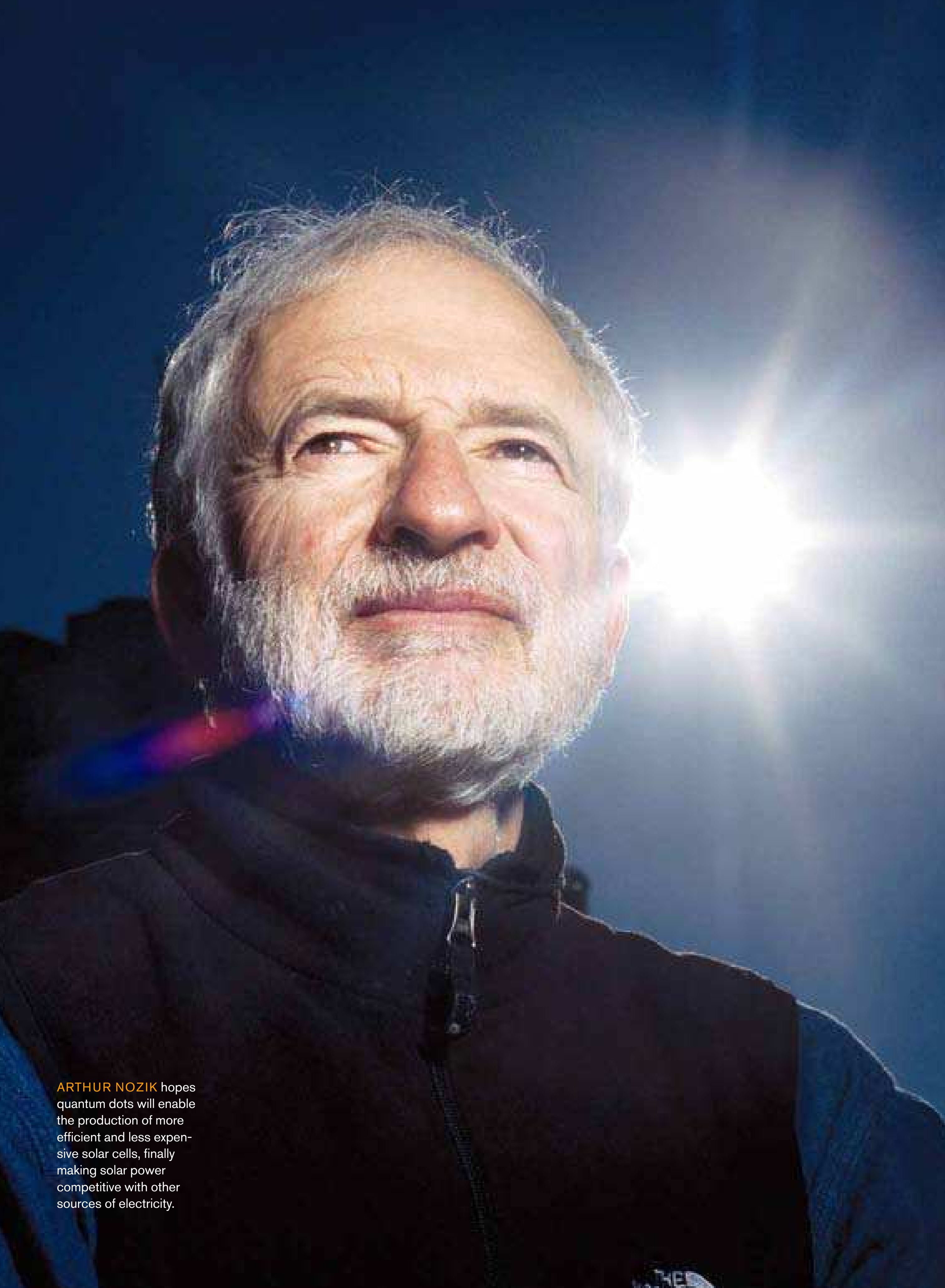
For Zhang and other P2P proponents, it's all a question of architecture. Conventionally, video and other Web content gets to consumers along paths that resemble trees, with the content owners' central servers as the trunks, multiple "content distribution servers" as the branches, and consumers' PCs as the leaves. Tree architectures work well enough, but they have three key weaknesses: If one branch is cut off, all its leaves go with it. Data flows in only one direction, so the leaves'—the PCs'—capacity to upload data goes untapped. And perhaps most important, adding new PCs to the network merely increases its congestion—and the demands placed on the servers.

In P2P networks, by contrast, there are no central servers: each user's PC exchanges data with many others in an ever-shifting mesh. This means that servers and their overtaxed network connections bear less of a burden; data is instead provided by peers, saving bandwidth in the Internet's core. If one user leaves the mesh, others can easily fill the gap. And adding users actually *increases* a P2P network's power.

There are just two big snags keeping content distributors and their ISPs from warming to mesh architectures. First, to balance the load on individual PCs, the most advanced P2P networks, such as BitTorrent, break big files into blocks, which are scattered across many machines. To reassemble those blocks, a computer on the network must use precious bandwidth to broadcast "metadata" describing which blocks it needs and which it already has.

Second, ISPs are loath to carry P2P traffic, because it's a big money-loser. For conventional one-way transfers, ISPs can charge content owners such as Google or NBC.com according to the amount of bandwidth they consume. But P2P traffic is generated by subscribers themselves, who usually pay a flat monthly fee regardless of how much data they download or upload.

Zhang and others believe they're close to solving both problems. At Cornell University, computer scientist Paul



ARTHUR NOZIK hopes quantum dots will enable the production of more efficient and less expensive solar cells, finally making solar power competitive with other sources of electricity.

Francis is testing a P2P system called Chunkyspread that combines the best features of trees and meshes. Members' PCs are arranged in a classic tree, but they can also connect to one another, reducing the burden on the branches.

Just as important, Chunkyspread reassembles files in "slices" rather than blocks. A slice consists of the *n*th bit of every block—for example, the fifth bit in every block of 20 bits. Alice's PC might obtain a commitment from Bob's PC to send bit five from every block it possesses, from Carol's PC to send bit six, and so forth. Once these commitments are made, no more metadata need change hands, saving bandwidth. In simulations, Francis says, Chunkyspread far outperforms simple tree-based multicast methods.

Zhang thinks new technology can also make carrying P2P traffic more palatable for ISPs. Right now, operators have little idea what kind of data flows through their networks. At his Pittsburgh-based stealth startup, Rinera Networks, Zhang is developing software that will identify P2P data, let ISPs decide how much of it they're willing to carry, at what volume and price, and then deliver it as reliably as server-based content distribution systems do—all while tracking everything for accounting purposes. "We want to build an ecosystem such that service providers will actually benefit from P2P traffic," Zhang explains. Heavy P2P users might end up paying extra fees—but in the end, content owners and consumers won't gripe, he argues, since better accounting should make the Internet function more effectively for everyone.

If this smells like a violation of the Internet's tradition of network neutrality—the principle that ISPs should treat all bits equally, regardless of their origin—then it's because the tradition needs to be updated for an era of very large file transfers, Zhang believes. "It's all about volume," he says. "Of course, we don't want the service providers to dictate what they will carry on their infrastructure. On the other hand, if P2P users benefit from transmitting and receiving more bits, the guys who are actually transporting those bits should be able to share in that."

Networking and hardware companies have their eyes on technologies emerging from places like Rinera and Francis's Cornell lab, even as they build devices designed to help consumers download video and other files over P2P networks. Manufacturers Asus, Planex, and QNAP, for example, are working with BitTorrent to embed the company's P2P software in their home routers, media servers, and storage devices. With luck, Senator Stevens's tubes may stay unblocked a little longer.

ENERGY

Nanocharging Solar

Arthur Nozik believes quantum-dot solar power could boost output in cheap photovoltaics. By David Talbot

No renewable power source has as much theoretical potential as solar energy. But the promise of cheap and abundant solar power remains unmet, largely because today's solar cells are so costly to make.

Photovoltaic cells use semiconductors to convert light energy into electrical current. The workhorse photovoltaic material, silicon, performs this conversion fairly efficiently, but silicon cells are relatively expensive to manufacture. Some other semiconductors, which can be deposited as thin films, have reached market, but although they're cheaper, their efficiency doesn't compare to that of silicon. A new solution may be in the offing: some chemists think that quantum dots—tiny crystals of semiconductors just a few nanometers wide—could at last make solar power cost-competitive with electricity from fossil fuels.

By dint of their size, quantum dots have unique abilities to interact with light. In silicon, one photon of light frees one electron from its atomic orbit. In the late 1990s, Arthur Nozik, a senior research fellow at the National Renewable Energy Laboratory in Golden, CO, postulated that quantum dots of certain semiconductor materials could release two or more electrons when struck by high-energy photons, such as those found toward the blue and ultraviolet end of the spectrum.

In 2004, Victor Klimov of Los Alamos National Laboratory in New Mexico provided the first experimental proof that Nozik was right; last year he showed that quantum dots of lead selenide could produce up to seven electrons per photon when exposed to high-energy ultraviolet light. Nozik's team soon demonstrated the effect in dots made of other semiconductors, such as lead sulfide and lead telluride.

These experiments have not yet produced a material suitable for commercialization, but they do suggest that quantum dots could someday increase the efficiency of converting sunlight into electricity. And since quantum dots can be made using simple chemical reactions, they could also make solar cells far less expensive. Researchers in Nozik's lab, whose results have not been published, recently demonstrated the extra-electron effect in quantum dots made of silicon; these dots would

LANCE W. CLAYTON

be far less costly to incorporate into solar cells than the large crystalline sheets of silicon used today.

To date, the extra-electron effect has been seen only in isolated quantum dots; it was not evident in the first prototype photovoltaic devices to use the dots. The trouble is that in a working solar cell, electrons must travel out of the semiconductor and into an external electrical circuit. Some of the electrons freed in any photovoltaic cell are inevitably "lost," recaptured by positive "holes" in the semiconductor. In quantum dots, this recapture happens far faster than it does in larger pieces of a semiconductor; many of the freed electrons are immediately swallowed up.

The Nozik team's best quantum-dot solar cells have managed only about 2 percent efficiency, far less than is needed for a practical device. However, the group hopes to boost the efficiency by modifying the surfaces of the quantum dots or improving electron transport between dots.

The project is a gamble, and Nozik readily admits that it might not pay off. Still, the enormous potential of the nanocrystals keeps him going. Nozik calculates that a photovoltaic device based on quantum dots could have a maximum efficiency of 42 percent, far better than silicon's maximum efficiency of 31 percent. The quantum dots themselves would be cheap to manufacture, and they could do their work in combination with materials like conducting polymers that could also be produced inexpensively. A working quantum dot–polymer cell could eventually place solar electricity on a nearly even economic footing with electricity from coal. "If you could [do this], you would be in Stockholm—it would be revolutionary," says Nozik.

A commercial quantum-dot solar cell is many years away, assuming it's even possible. But if it is, it could help put our fossil-fuel days behind us.

BIOTECHNOLOGY

Neuron Control

Karl Deisseroth's genetically engineered "light switch," which lets scientists turn selected parts of the brain on and off, may help improve treatments for depression and other disorders.

By Emily Singer

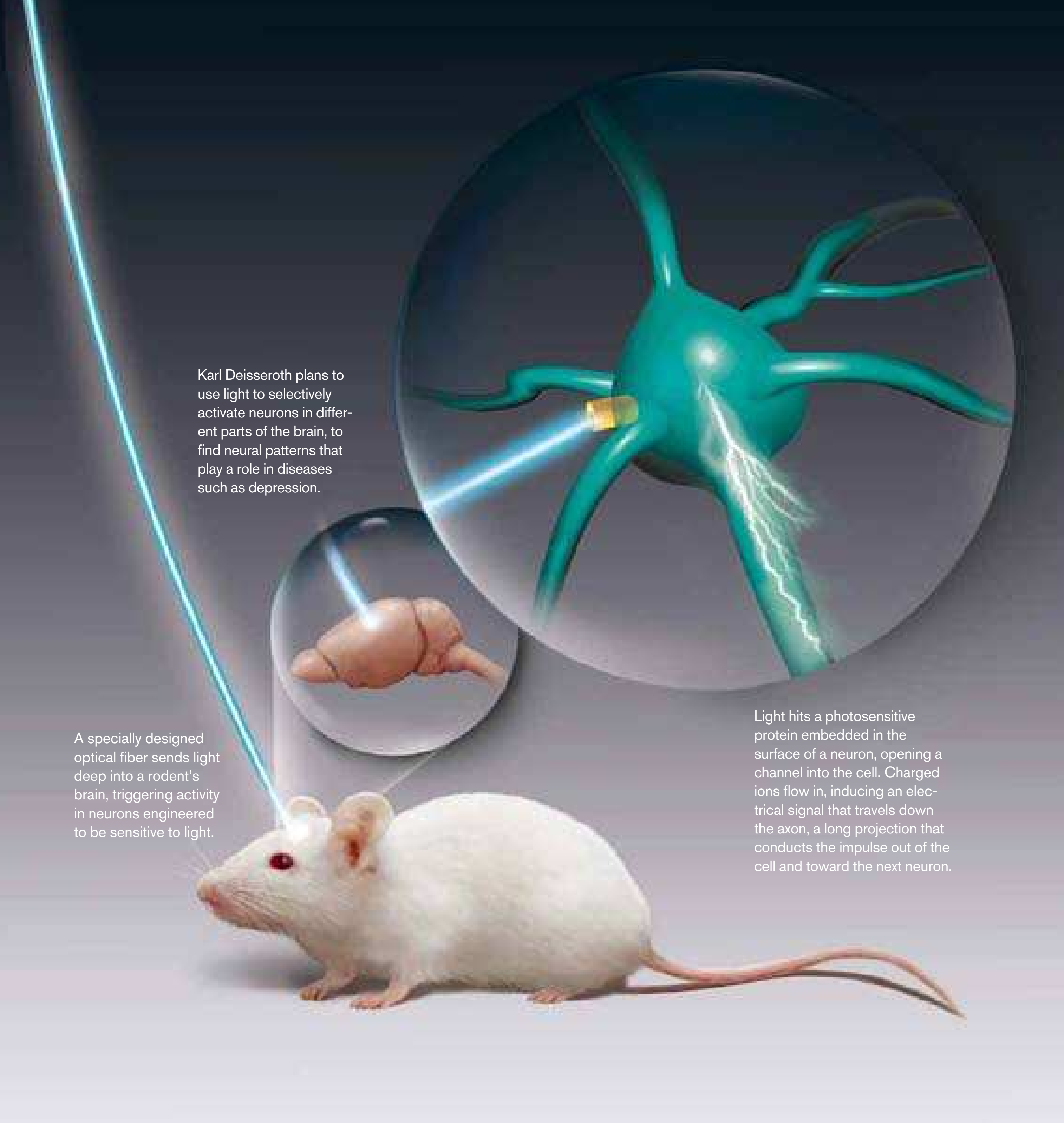
IN HIS PSYCHIATRY PRACTICE at the Stanford Medical Center, Karl Deisseroth sometimes treats patients who are so severely depressed that they can't walk, talk, or eat. Intensive treatments, such as electroconvulsive therapy, can literally save such patients' lives, but often at the cost of memory loss, headaches, and other serious side effects. Deisseroth, who is both a physician and a bioengineer, thinks he has a better way: an elegant new method for controlling neural cells with flashes of light. The technology could one day lead to precisely targeted treatments for psychiatric and neurological disorders; that precision could mean greater effectiveness and fewer side effects.

While scientists know something about the chemical imbalances underlying depression, it's still unclear exactly which cells, or networks of cells, are responsible for it. In order to identify the circuits involved in such diseases, scientists must be able to turn neurons on and off. Standard methods, such as electrodes that activate neurons with jolts of electricity, are not precise enough for this task, so Deisseroth, postdoc Ed Boyden (now an assistant professor at MIT; see "Engineering the Brain," p. 34), and graduate student Feng Zhang developed a neural controller that can activate specific sets of neurons.

They adapted a protein from a green alga to act as an "on switch" that neurons can be genetically engineered to produce *(see "Artificially Firing Neurons," TR35, September/October 2006)*. When the neuron is exposed to light, the protein triggers electrical activity within the cell that spreads to the next neuron in the circuit. Researchers can thus use light to activate certain neurons and look for specific responses—a twitch of a muscle, increased energy, or a wave of activity in a different part of the brain.

Deisseroth is using this genetic light switch to study the biological basis of depression. Working with a group of rats that show symptoms similar to those seen in depressed humans, researchers in his lab have inserted the switch into neurons in different brain areas implicated in depression. They then use an optical fiber to shine light onto those cells, looking for activity patterns that alleviate the symptoms. Deisseroth says the findings should help scientists develop better antidepressants: if they know exactly which cells to target, they can look for molecules or delivery systems that affect only those cells. "Prozac goes to all the circuits in the brain, rather than just the relevant ones," he says. "That's part of the reason it has so many side effects."

In the last year, Deisseroth has sent his switch to more than 100 research labs. "Folks are applying it to all kinds of animals, including mice, worms, flies, and zebrafish," he says. Scientists are using this and similar switches to study everything from movement to addiction to appetite. "These technologies allow us to advance from



ELAINE KURIE

observation to active intervention and control," says Gero Miesenböck, a neuroscientist at Yale University. By evoking sensations or movements directly, he says, "you can forge a much stronger connection between mental activity and behavior."

Deisseroth hopes his technology will one day become not just a research tool but a treatment in itself, used alongside therapies that electrically stimulate large areas of the brain to treat depression or Parkinson's disease. By activating only specific neurons, a specially engineered light switch could limit those therapies' side effects. Of course, the researchers will need to solve some problems first: they'll need to find safe gene-therapy methods for delivering the switch to the target cells, as well as a way to shine light deep into the brain. "It's a long way off," says Deisseroth. "But the obstacles aren't insurmountable." In the meantime, neuroscientists have the use of a powerful new tool in their quest to uncover the secrets of the brain.

NANOTECHNOLOGY

Nanohealing

Tiny fibers will save lives by stopping bleeding and aiding recovery from brain injury, says Rutledge Ellis-Behnke. By Kevin Bullis

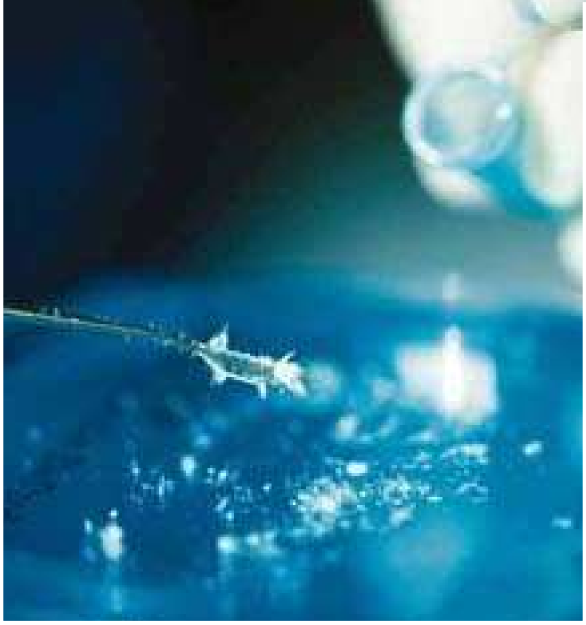
PHOTOGRAPHS BY ASIA KEPKA

In the break room near his lab in MIT's brand-new neuroscience building, research scientist Rutledge Ellis-Behnke provides impromptu narration for a video of himself performing surgery. In the video, Ellis-Behnke makes a deep cut in the liver of a rat, intentionally slicing through a main artery. As the liver pulses from the pressure of the rat's beating heart, blood spills from the wound. Then Ellis-Behnke covers the wound with a clear liquid, and the bleeding stops almost at once. Untreated, the wound would have proved fatal, but the rat lived on.

The liquid Ellis-Behnke used is a novel material made of nanoscale protein fragments, or peptides. Its ability to stop bleeding almost instantly could be invaluable in surgery, at accident sites, or on the battlefield. Under conditions like those inside the body, the peptides self-assemble into a fibrous mesh that to the naked eye appears to be a transparent gel. Even more remarkably, the material creates an environment that may accelerate healing of damaged brain and spinal tissue.

Ellis-Behnke stumbled on the material's capacity to stanch bleeding by chance, during experiments designed to help restore vision to brain-damaged hamsters. And his discovery was itself made possible by earlier serendipitous events. In the early 1990s, Shuguang Zhang, now a biomedical engineer at MIT, was working in the lab of MIT biologist Alexander Rich. Zhang had been studying a repeating DNA sequence that coded for a peptide. He and a colleague inadvertently found that under certain conditions, copies of the peptide would combine into fibers. Zhang and his colleagues began to reëngineer the peptides to exhibit specific responses to electric charges and water. They ended up with a 16-amino-acid peptide that looks like a comb, with water-loving teeth projecting from a water-repelling spine. In a salty, aqueous environment—such as that inside the body—the spines spontaneously cluster together to avoid the water, forming long, thin fibers that self-assemble into curved ribbons. The process transforms a liquid peptide solution into a clear gel.

Originally, Ellis-Behnke intended to use the material to promote the healing of brain and spinal-cord injuries. In young animals, neurons are surrounded by materials that help them grow; Ellis-Behnke thought that the peptide gel could create a similar environment and prevent the formation of scar tissue, which obstructs the regrowth of severed neurons. "It's like if you're walking through a field of wheat, you can walk easily because the wheat moves out of the way," he

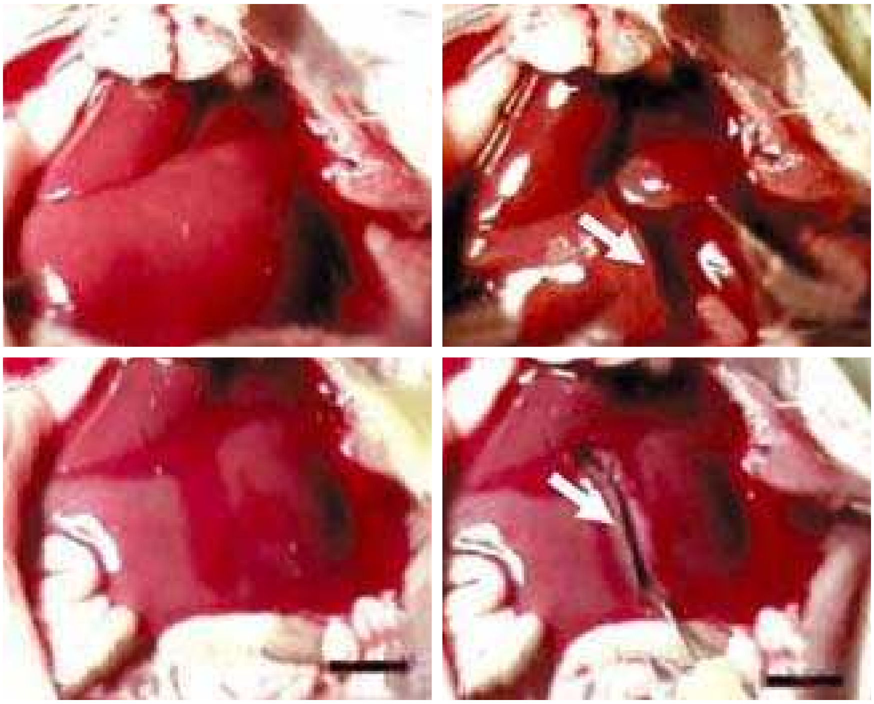


says. "If you're walking through a briar patch, you get stuck." In the hamster experiments, the researchers found that the gel allowed neurons in a vision-related tract of the brain to grow across a lesion and reëstablish connections with neurons on the other side, restoring the hamster's sight.

It was during these experiments that Ellis-Behnke discovered the gel's ability to stanch bleeding. Incisions had been made in the hamsters' brains, but when the researchers applied the new material, all residual bleeding suddenly stopped. At first, Ellis-Behnke says, "we thought that we'd actually killed the animals. But the heart was still going." Indeed, the rodents survived for months, apparently free of negative side effects.

The material has several advantages over current methods for stopping bleeding. It's faster and easier than cauterization and does not damage tissue. It could protect wounds from the air and supply amino-acid building blocks to growing cells, thereby accelerating healing. Also, within a few weeks the body completely breaks the peptides down, so they need not be removed from the wound, unlike some other blood-stanching agents. The syn-

Rutledge Ellis-Behnke (opposite page) mixes a powder of short, engineered chains of amino acids (top left) with deionized water to form a clear solution (in vials, above). When the solution is exposed to salt water, as in the petri dishes above, the peptides form an invisible mesh, which changes the liquid into a gel. One dish (center) contains a 1 percent peptide solution, which is more fluid than a 3 percent solution (inset). The gel also forms when the peptide solution is exposed to blood, stanching bleeding. Higher concentrations may help stop more serious bleeding.



BLEEDING STOPS after a solution of engineered peptides is applied to a wound in a rat's liver. The arrow (top right) points to a deep cut. It bleeds (bottom left) until the solution is poured onto the wound. The solution forms a transparent gel (bottom right) that prevents the blood from flowing. The bleeding stops completely just 8.6 seconds after the wound is made.

thetic material also has a long shelf life, which could make it particularly useful in first-aid kits.

The material's first application will probably come in the operating room. Not only would it stop the bleeding caused by surgical incisions, but it could also form a protective layer over wounds. And since the new material is transparent, surgeons should be able to apply a layer of it and then operate through it. "When you perform surgery, you are constantly suctioning and cleaning the site to be able to see it," says Ram Chuttani, a gastroenterologist and professor at Harvard Medical School. "But if you can seal it, you can continue to perform the surgery with much clearer vision." The hope is that surgeons will be able to operate faster, thus reducing complications. The material may also make it possible to perform more procedures in a minimally invasive way by allowing a surgeon to quickly stop bleeding at the end of an endoscope.

Chuttani, who was not involved with the research, cautions that the work is still "very preliminary," with no tests yet on large animals or humans. But if such tests go well, Ellis-Behnke estimates, the material could be approved for use in humans in three to five years. "I don't know what the impact is going to be," he says. "But if we can stop bleeding, we can save a lot of people." Ellis-Behnke and his colleagues are also continuing to explore the material's nerve regeneration capabilities. They're looking for ways to increase the rate of neuronal growth so that doctors can treat larger brain injuries, such as those that can result from stroke. But such a treatment will take at least five to ten years to reach humans, Ellis-Behnke says.

Even without regenerating nerves, the material could save countless lives in surgery or at accident sites. And already, the material's performance is encouraging research by demonstrating how engineering nanostructures to self-assemble in the body could profoundly improve medicine.

TELECOM

Augmented Reality

Markus Kähäri wants to superimpose digital information on the real world. By Erika Jonietz

FINDING YOUR WAY around a new city can be exasperating: juggling maps and guidebooks, trying to figure out where you are on roads with no street signs, talking with locals who give directions by referring to unfamiliar landmarks. If you're driving, a car with a GPS navigation system can make things easier, but it still won't help you decide, say, which restaurant suits both your palate and your budget. Engineers at the Nokia Research Center in Helsinki, Finland, hope that a project called Mobile Augmented Reality Applications will help you get where you're going—and decide what to do once you're there.

Last October, a team led by Markus Kähäri unveiled a prototype of the system at the International Symposium on Mixed and Augmented Reality. The team added a GPS sensor, a compass, and accelerometers to a Nokia smart phone. Using data from these sensors, the phone can calculate the location of just about any object its camera is aimed at. Each time the phone changes location, it retrieves the names and geographical coördinates of nearby landmarks from an external database. The user can then download additional information about a chosen location from the Web—say, the names of businesses in the Empire State Building, the cost of visiting the building's observatories, or hours and menus for its five eateries.

The Nokia project builds on more than a decade of academic research into mobile augmented reality. Steven

COURTESY OF RUTLEDGE ELLIS-BEHNKE (BLEEDING); PHOTO ILLUSTRATION BY JEAN PROBERT (REALITY)

In Nokia's mobile-augmented-reality prototype, a user can point a phone's camera at a nearby building; the system calculates the building's location and uses that information to identify it.

Boxes appear on the phone's screen, highlighting known businesses and landmarks, such as the Empire State Building. The user can click one of these boxes to download information about that location from the Web.

Feiner, the director of Columbia University's Computer Graphics and User Interfaces Laboratory, undertook some of the earliest research in the field and finds the Nokia project heartening. "The big missing link when I started was a small computer," he says. "Those small computers are now cell phones."

Despite the availability and fairly low cost of the sensors the Nokia team used, some engineers believe that they introduce too much complexity for a commercial application. "In my opinion, this is very exotic hardware to provide," says Valentin Lefevre, chief technology officer and cofounder of Total Immersion, an augmented-reality company in Suresnes, France. "That's why we think picture analysis is the solution." Relying on software alone, Total Immersion's system begins with a single still image of whatever object the camera is aimed at, plus a rough digital model of that object; image-recognition algorithms then determine what data should be superimposed on the image. The company is already marketing a mobile version of its system to cell-phone operators in Asia and Europe and expects the system's first applications to be in gaming and advertising.

Nokia researchers have begun working on real-time image-recognition algorithms as well; they hope the algorithms will eliminate the need for location sensors and improve their system's accuracy and reliability. "Methods that don't rely on those components can be more robust," says Kari Pulli, a research fellow at the Nokia Research Center in Palo Alto, CA.

All parties agree, though, that mobile augmented reality is nearly ready for the market. "For mobile-phone applications, the technology is here," says Feiner. One challenge is convincing carriers such as Sprint or Verizon that customers would pay for augmented-reality services. "If some big operator in the U.S. would launch this, it could fly today," Pulli says.

NANOTECHNOLOGY

Invisible Revolution

Artificially structured metamaterials could transform telecommunications, data storage, and even solar energy, says David R. Smith. By Philip Ball

The announcement last November of an "invisibility shield," created by David R. Smith of Duke University and colleagues, inevitably set the media buzzing with talk of H. G. Wells's invisible man and *Star Trek*'s Romulans. Using rings of printed circuit boards, the researchers managed to divert microwaves around a kind of "hole in space"; even when a metal cylinder was placed at the center of the hole, the microwaves behaved as though nothing were there.

It was arguably the most dramatic demonstration so far of what can be achieved with metamaterials, composites made up of precisely arranged patterns of two or more distinct materials. These structures can manipulate electromagnetic radiation, including light, in ways not readily observed in nature. For example, photonic crystals—arrays of identical microscopic blocks separated by voids—can reflect or even inhibit the propagation of certain wavelengths of light; assemblies of small wire circuits, like those Smith used in his invisibility shield, can bend light in strange ways.

But can we really use such materials to make objects seem to vanish? Philip Ball spoke with Smith, who explains why metamaterials are literally changing the way we view the world.

TR: How do metamaterials let you make things invisible?

Smith: It's a somewhat complicated procedure but can be very simple to visualize. Picture a fabric formed from interwoven threads, in which light is constrained to travel along the threads. Well, if you now take a pin and push it through the fabric, the threads are distorted, making a hole in the fabric. Light, forced to follow the threads, is routed around the hole. John Pendry at Imperial College in London calculated what would be required of a metamaterial that would accomplish exactly this. The waves are transmitted around the hole and combined on the other side. So you can put an object in the hole, and the waves won't "see" it—it's as if they'd crossed a region of empty space.

And then you made it?

Yes—once we had the prescription, we set about using the techniques we'd developed over the past few years to make the material. We did the experiment at microwave frequencies because the techniques are very well established there and we knew we would be able to produce a demonstration quickly. We printed millimeter-scale metal wires and split rings, shaped like the letter C, onto fiberglass circuit boards. The shield consisted of about 10 concentric cylinders made up of these split-ring building blocks, each with a slightly different pattern.

So an object inside the shield is actually invisible?

More or less, but when we talk about invisibility in these structures, it's not about making things vanish before our eyes—at least, not yet. We can hide them from microwaves, but the shield is plain enough to see. This isn't like stealth shielding on military aircraft, where you just try to eliminate reflection—the microwaves seem literally to pass

DAVID R. SMITH (above) led the team that built the world's first "invisibility shield" (left). The shield consists of concentric circles of fiberglass circuit boards, printed with C-shaped split rings. Microwaves of a particular frequency behave as if objects inside the cylinder aren't there—but everything remains in plain view.

DAVID DEAL

through the object inside the shield. If this could work with visible light, then you really would see the object vanish.

Could you hide a large object, like an airplane, from radar by covering its surface with the right metamaterial?

I'm not sure we can do that. If you look at stealth technology today, it's generally interested in hiding objects from detection over a large radar bandwidth. But the invisibility bandwidth is inherently limited in our approach. The same is true for hiding objects from all wavelengths of visible light—that would certainly be a stretch.

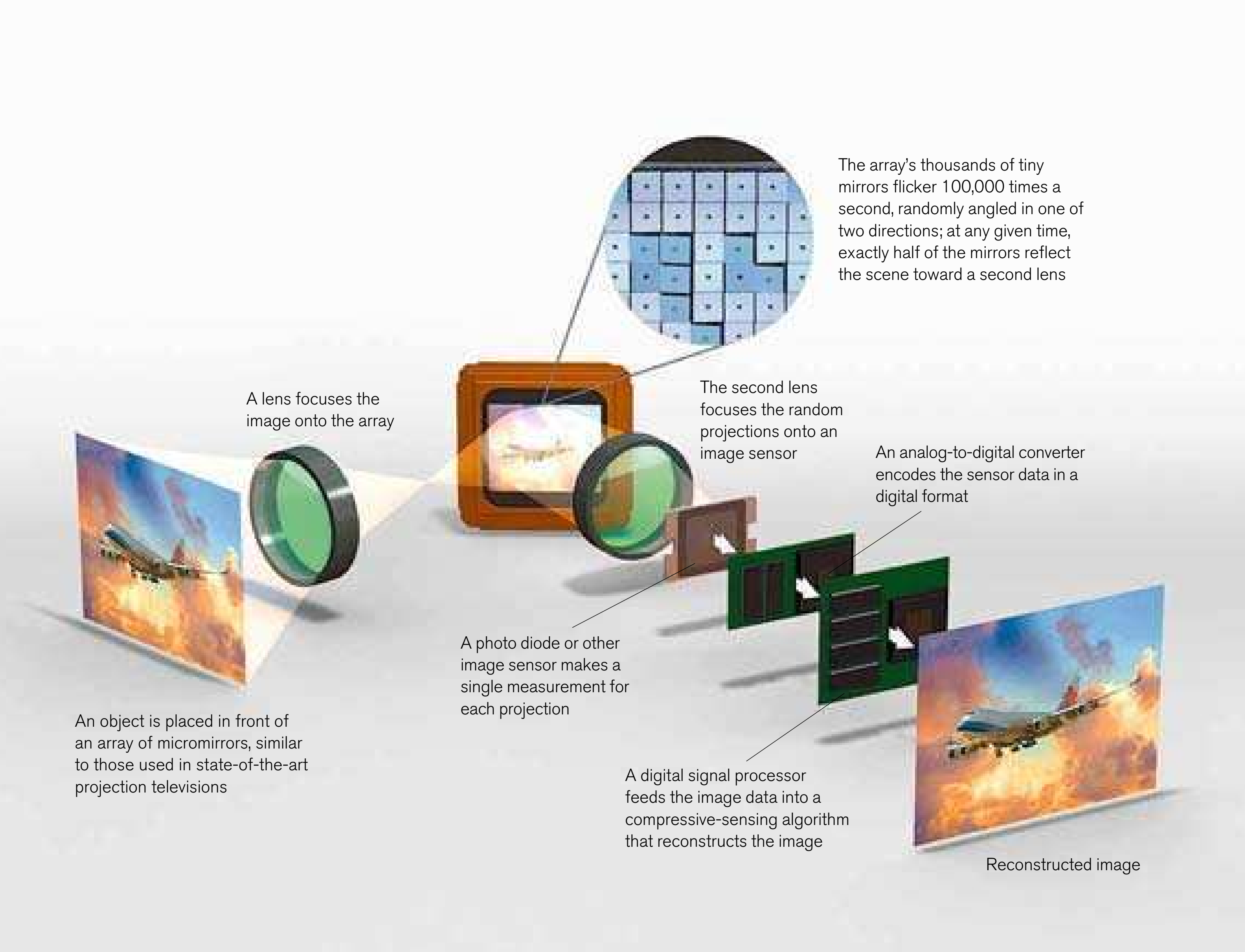
How else might we use metamaterials?

Well, this is really an entirely new approach to optics. There's a huge amount of freedom for design, and as is usual with new technology, the best uses probably haven't been thought of yet.

One of the most provocative and controversial predictions came from John Pendry, who predicted that a material with a negative refractive index could focus light more finely than any conventional lens material. The refractive index measures how much light bends when it passes through a material—that's what makes a pole dipped in water look as though it bends. A negative refractive index means the material bends light the "wrong" way. So far, we and others have been working not with visible light but with microwaves, which are also electromagnetic radiation, but with a longer wavelength. This means the components of the metamaterial must be correspondingly bigger, and so they're much easier to make. Pendry's suggestion was confirmed in 2005 by a group from the University of California, Berkeley, who made a negative-refractive-index metamaterial for microwaves.

Making a negative-index material that works for visible light is more difficult, because the building blocks have to be much smaller—no bigger than 10 to 20 nanometers. That's now very possible to achieve, however, and several groups are working on it. If it can be done, these metamaterials could be used to increase the amount of information stored on CDs and DVDs or to speed up transmission and reduce power consumption in fiber-optic telecommunications.

We can also concentrate electromagnetic fields—the exact opposite of what the cloak does—which might be valuable in energy-harvesting applications. With a suitable metamaterial, we could concentrate light coming from any direction—you wouldn't need direct sunlight. Right now we're trying to design structures like this. If we could achieve that for visible light, it could make solar power more efficient.



JOHN MACNEILL

SOFTWARE

Digital Imaging, Reimagined

Richard Baraniuk and Kevin Kelly believe compressive sensing could help devices such as cameras and medical scanners capture images more efficiently. By Kate Greene

RICHARD BARANIUK and Kevin Kelly have a new vision for digital imaging: they believe an overhaul of both hardware and software could make cameras smaller and faster and let them take incredibly high-resolution pictures.

Today's digital cameras closely mimic film cameras, which makes them grossly inefficient. When a standard four-megapixel digital camera snaps a shot, each of its four million image sensors characterizes the light striking it with a single number; together, the numbers describe a picture. Then the camera's onboard computer compresses the picture, throwing out most of those numbers. This process needlessly chews through the camera's battery.

Baraniuk and Kelly, both professors of electrical and computer engineering at Rice University, have developed a camera that doesn't need to compress images. Instead, it uses a single image sensor to collect just enough information to let a novel algorithm reconstruct a high-resolution image.

At the heart of this camera is a new technique called compressive sensing. A camera using the technique needs only a small percentage of the data that today's digital cameras must collect in order to build a comparable picture. Baraniuk and Kelly's algorithm turns visual data into a handful of numbers that it randomly inserts into a giant grid. There are just enough numbers to enable the algorithm to fill in the blanks, as we do when we solve a Sudoku puzzle. When the computer solves this puzzle, it has effectively re-created the complete picture from incomplete information.

Compressive sensing began as a mathematical theory whose first proofs were published in 2004; the Rice group has produced an advanced demonstration in a relatively short time, says Dave Brady of Duke University. "They've

really pushed the applications of the theory," he says.

Kelly suspects that we could see the first practical applications of compressive sensing within two years, in MRI systems that capture images up to 10 times as quickly as today's scanners do. In five to ten years, he says, the technology could find its way into consumer products, allowing tiny mobile-phone cameras to produce high-quality, poster-size images. As our world becomes increasingly digital, compressive sensing is set to improve virtually any imaging system, providing an efficient and elegant way to get the picture.

MEDICINE

Personalized Medical Monitors

John Guttag says using computers to automate some diagnostics could make medicine more personal.

By Jennifer Chu

In late spring 2000, John Guttag came home from surgery. It had been a simple procedure to repair a torn ligament in his knee, and he had no plans to revisit the hospital anytime soon. But that same day his son, then a junior in high school, complained of chest pains. Guttag's wife promptly got back in the car and returned to the hospital, where their son was diagnosed with a collapsed lung and immediately admitted. Over the next year, Guttag and his wife spent weeks at a time in and out of the hospital with their son, who underwent multiple surgeries and treatments for a series of recurrences.

During that time, Guttag witnessed what became a familiar scenario. "The doctors would come in, take a stethoscope, listen to his lungs, and make a pronouncement like 'He's 10 percent better than yesterday,' and I wanted to say, 'I don't believe that,'" he says. "You can't possibly sit there and listen with your ears and tell me you can hear a 10 percent difference. Surely there's a way to do this more precisely."

It was an observation that any concerned parent might make, but for Guttag, who was then head of MIT's Department of Electrical Engineering and Computer Science, it was a personal challenge. "Health care just seemed like an area that was tremendously in need of our expertise," he says.

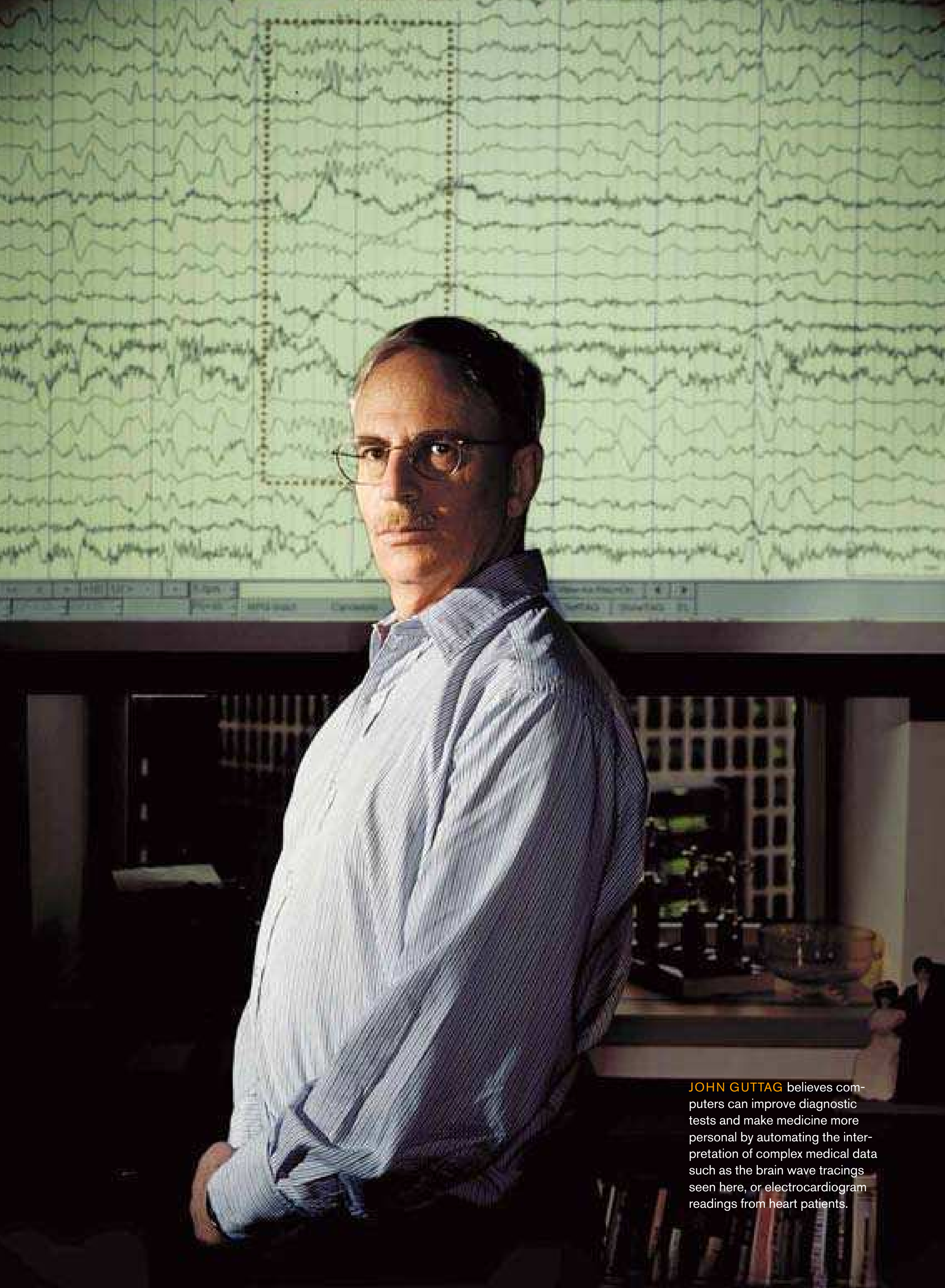
The ripest challenge, Guttag says, is analyzing the huge amounts of data generated by medical tests. Today's physicians are bombarded with physiological information—temperature and blood pressure readings, MRI scans, electrocardiogram (EKG) readouts, and x-rays, to name a few. Wading through a single patient's record to determine signs of, say, a heart attack or stroke can be difficult and time consuming. Guttag believes computers can help doctors efficiently interpret these ever-growing masses of data. By quickly perceiving patterns that might otherwise be buried, he says, software may provide the key to more precise and personalized medicine. "People aren't good at spotting trends unless they're very obvious," says Guttag. "It dawned on me that doctors were doing things that a computer could do better."

For instance, making sense of the body's electrical signals seemed, to Guttag, to be a natural fit for computer science. Some of his earlier work on computer networks caught the attention of physicians at Children's Hospital Boston. The doctors and the engineer set out to improve the detection of epileptic seizures; ultimately, Guttag and graduate student Ali Shoeb designed personalized seizure detectors. In 2004, the team examined recordings of the brain waves of more than 30 children with epilepsy, before, during, and after seizures. They used the data to train a "classification algorithm" to distinguish between seizure and nonseizure waveforms. With the help of the algorithm, the researchers identified seizure patterns specific to each patient.

The team is now working on a way to make that type of information useful to people with epilepsy. Today, many patients can control their seizures with an implant that stimulates the vagus nerve. The implant typically works in one of two ways: either it turns on every few minutes, regardless of a patient's brain activity, or patients sweep a magnet over it, activating it when they sense a seizure coming on. Both methods have their drawbacks, so Guttag is designing a noninvasive, software-driven sensor programmed to measure the wearer's brain waves and determine what patterns—specific to him or her—signify the onset of a seizure. Once those patterns are detected, a device can automatically activate an implant, stopping the seizure in its tracks.

Guttag plans to test the sensor, essentially a bathing cap of electrodes that fits over the scalp, on a handful of patients at Beth Israel Deaconess Medical Center this spring. Down the line, such a sensor could also help people without implants, simply warning them to sit down, pull over, or get to a safe place before a seizure begins. "Just a warning could be enormously life changing," says Guttag. "It's all the collateral damage that people really fear."

Now he's turned his attention to patterns of the heart. Like the brain, cardiac activity is governed by electrical signals, so moving into cardiology is a natural transition for Guttag.



JOHN GUTTAG believes computers can improve diagnostic tests and make medicine more personal by automating the interpretation of complex medical data such as the brain wave tracings seen here, or electrocardiogram readings from heart patients.

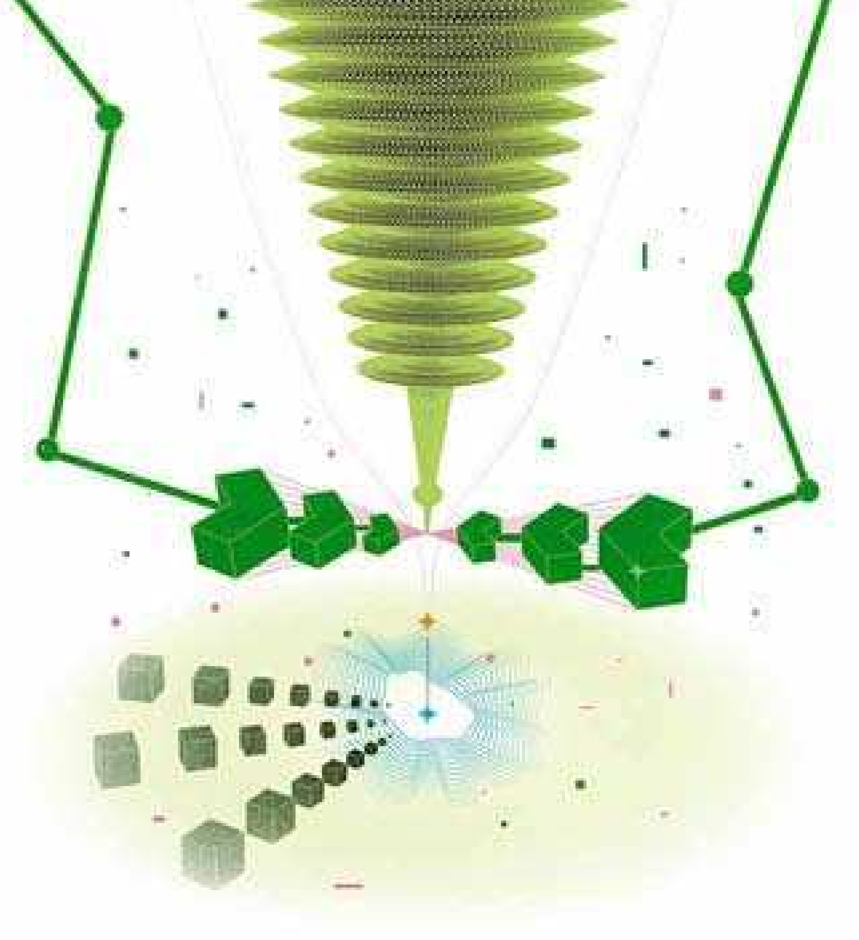
He began by looking for areas where large-scale cardiac-data analysis was needed. Today, many patients who have suffered heart attacks go home with Holter monitors that record heart activity. After a day or so, a cardiologist reviews the monitor's readings for worrisome signs. But it can be easy to miss an abnormal pattern in thousands of minutes of dense waveforms.

That's where Guttag hopes computers can step in. Working with Collin Stultz, a cardiologist and assistant professor of electrical engineering and computer science at MIT, and graduate student Zeeshan Syed, Guttag is devising algorithms to analyze EKG readings for statistically meaningful patterns. In the coming months, the team will compare EKG records from hundreds of heart attack patients, some of whose attacks were fatal. The immediate goal is to pick out key similarities and differences between those who survived and those who didn't. There are known "danger patterns" that physicians can spot on an EKG readout, but the Guttag group is leaving it up to the computer to find significant patterns, rather than telling it what to look for. If the computer's search isn't influenced by existing medical knowledge, Guttag reasons, it may uncover unexpected relationships.

Joseph Kannry, director of the Center for Medical Informatics at the Mount Sinai School of Medicine, calls Guttag's work a solid step toward developing more accurate automated medical readings. "It's promising. The challenge is going to be in convincing a clinician to use it," says Kannry.

Still, Guttag feels he is well on his way toward integrating computing into medical diagnostics. "People have very different reactions when you tell them computers are going to make decisions for you," he says. "But we've gotten to the point where computers fly our airplanes for us, so there's every reason to be optimistic."

MAX AGUILERA-HELLWEG (GUTTAG); JOHN HERSEY (LIGHT)



NANOTECHNOLOGY

A New Focus for Light

Kenneth Crozier and Federico Capasso have created light-focusing optical antennas that could lead to DVDs that hold hundreds of movies. By Katherine Bourzac

RESEARCHERS TRYING to make high-capacity DVDs, as well as more-powerful computer chips and higher-resolution optical microscopes, have for years run up against the "diffraction limit." The laws of physics dictate that the lenses used to direct light beams cannot focus them onto a spot whose diameter is less than half the light's wavelength. Physicists have been able to get around the diffraction limit in the lab—but the systems they've devised have been too fragile and complicated for practical use. Now Harvard University electrical engineers led by Kenneth Crozier and Federico Capasso have discovered a simple process that could bring the benefits of tightly focused light beams to commercial applications. By adding nanoscale "optical antennas" to a commercially available laser, Crozier and Capasso have focused infrared light onto a spot just 40 nanometers wide—one-twentieth the light's wavelength. Such optical antennas could one day make possible DVD-like discs that store 3.6 terabytes of data—the equivalent of more than 750 of today's 4.7-gigabyte recordable DVDs.

Crozier and Capasso build their device by first depositing an insulating layer onto the light-emitting edge of the laser. Then they add a layer of gold. They carve away most of the gold, leaving two rectangles of only 130 by 50 nanometers, with a 30-nanometer gap between them. These form an antenna. When light from the laser strikes the rectangles, the antenna has what Capasso calls a "lightning-rod effect": an

intense electrical field forms in the gap, concentrating the laser's light onto a spot the same width as the gap.

"The antenna doesn't impose design constraints on the laser," Capasso says, because it can be added to off-the-shelf semiconductor lasers, commonly used in CD drives. The team has already demonstrated the antennas with several types of lasers, each producing a different wavelength of light. The researchers have discussed the technology with storage-device companies Seagate and Hitachi Global Storage Technologies.

Another application could be in photolithography, says Gordon Kino, professor emeritus of electrical engineering at Stanford University. This is the method typically used to make silicon chips, but the lasers that carve out ever-smaller features on silicon are also constrained by the diffraction limit. Electron-beam lithography, the technique that currently allows for the smallest chip features, requires a large machine that costs millions of dollars and is too slow to be used in mass production. "This is a hell of a lot simpler," says Kino of Crozier and Capasso's technique, which relies on a laser that costs about $50.

But before the antennas can be used for lithography, the engineers will need to make them even smaller: the size of the antennas must be tailored to the wavelength of the light they focus. Crozier and Capasso's experiments have used infrared lasers, and photolithography relies on shorter-wavelength ultraviolet light. In order to inscribe circuitry on microchips, the researchers must create antennas just 50 nanometers long.

Capasso and Crozier's optical antennas could have far-reaching and unpredictable implications, from superdense optical storage to superhigh-resolution optical microscopes. Enabling engineers to simply and cheaply break the diffraction limit has made the many applications that rely on light shine that much brighter.

BIOTECHNOLOGY

Single-Cell Analysis

Norman Dovichi believes that detecting minute differences between individual cells could improve medical tests and treatments. By Jon Cohen

We all know that focusing on the characteristics of a group can obscure the differences between the individuals in it. Yet when it comes to biological cells, scientists typically derive information about their behavior, status, and health from the collective activity of thousands or millions of them. A more precise understanding of differences between individual cells could lead to better treatments for cancer and diabetes, just for starters.

The past few decades have seen the advent of methods that allow astonishingly detailed views of single cells—each of which can produce thousands of different proteins, lipids, hormones, and metabolites. But most of those methods have a stark limitation: they rely on "affinity reagents," such as antibodies that attach to specific proteins. As a result, researchers can use them to study only what's known to exist. "The unexpected is invisible," says Norman Dovichi, an analytical chemist at the University of Washington, Seattle. And most every cell is stuffed with mysterious components. So Dovichi has helped pioneer ultrasensitive techniques to isolate cells and reveal molecules inside them that no one even knew were there.

Dovichi's lab—one of a rapidly growing number of groups that focus on single cells—has had particular success at identifying differences in the amounts of dozens of distinct proteins produced by individual cancer cells. "Ten years ago, I would have thought it would have been almost impossible to do that," says Robert Kennedy, an analytical chemist at the University of Michigan–Ann Arbor, who analyzes insulin secretion from single cells to uncover the causes of the most common type of diabetes.

And Dovichi has a provocative hypothesis: he thinks that as a cancer progresses, cells of the same type diverge more and more widely in their protein content. If this proves true, then vast dissimilarities between cells would indicate a disease that is more likely to spread. Dovichi is working with clini-

ELAINE KURIE

ANALYZING INDIVIDUAL CELLS allows researchers to distinguish between a uniform population of cells (left) and a group of cells with members having, say, different protein content (right). The ability to recognize such differences could be essential to understanding diseases such as cancer or diabetes.

cians to develop better prognostics for esophageal and breast cancer based on this idea. Ultimately, such tests could let doctors quickly decide on proper treatment, a key to defeating many cancers.

A yellow, diamond-shaped sign in Dovichi's office warns that a "laser jock" is present. Dovichi helped develop the laser-based DNA sequencers that became the foundation of the Human Genome Project, and his new analyzers rely on much of the same technology to probe single cells for components that are much harder to detect than DNA: proteins, lipids, and carbohydrates.

For proteins, the machines mix reagents with a single cell inside an ultrathin capillary tube. A chemical reaction causes lysine, an amino acid recurring frequently in proteins, to fluoresce. The proteins, prodded by an electric charge, migrate out of the tube at different rates, depending on their size. Finally, a laser detector records the intensity of the fluorescence. This leads to a graphic that displays the various amounts of the different-sized proteins inside the cell.

Although the technique reveals differences between cells, it does not identify the specific proteins. Still, the analyzer has an unprecedented sensitivity and makes visible potentially critical differences. "For our cancer prognosis projects, we don't need to know the identity of the components," Dovichi says.

Dovichi is both excited about the possibilities of single-cell biology and sober about its limitations. Right now, he says, analyses take too much time and effort. "This is way early-stage," says Dovichi. "But hopefully, in 10, 20, or 30 years, people will look back and say those were interesting baby steps." TR

A Smarter Web

New technologies will make online search more intelligent—and may even lead to a "Web 3.0."

By John Borland

Illustrations by Polly Becker

Last year, Eric Miller, an MIT-affiliated computer scientist, stood on a beach in southern France, watching the sun set, studying a document he'd printed earlier that afternoon. A March rain had begun to fall, and the ink was beginning to smear.

Five years before, he'd agreed to lead a diverse group of researchers working on a project called the Semantic Web, which seeks to give computers the ability—the seeming intelligence—to understand content on the World Wide Web. At the time, he'd made a list of goals, a copy of which he now held in his hand. If he'd achieved those goals, his part of the job was done.

Taking stock on the beach, he crossed off items one by one. The Semantic Web initiative's basic standards were in place; big companies were involved; startups were merging or being purchased; analysts and national and international newspapers, not just technical publications, were writing about the project. Only a single item remained: taking the technology mainstream. Maybe it was time to make this happen himself, he thought. Time to move into the business world at last.

"For the Semantic Web, it was no longer a matter of if but of when," Miller says. "I felt I could be more useful by helping people get on with it."

Now, six months after the launch of his own Zepheira, a consulting company that helps businesses link fragmented data sources into easily searched wholes, Miller's beachside decision seems increasingly prescient. The Semantic Web community's grandest visions, of data-surfing computer servants that automatically reason their way through problems, have yet to be fulfilled. But the basic technologies that Miller shepherded through research labs and standards committees are joining the everyday Web. They can be found everywhere—on entertainment and travel sites, in business and scientific databases—and are forming the core of what some promoters call a nascent "Web 3.0."

Already, these techniques are helping developers stitch together complex applications or bring once-inaccessible data sources online. Semantic Web tools now in use improve and automate database searches, helping people choose vacation destinations or sort through complicated financial data more efficiently. It may be years before the Web is populated by truly intelligent software agents automatically doing our bidding, but their precursors are helping people find better answers to questions today.

The "3.0" claim is ambitious, casting these new tools as successors to several earlier—but still viable—generations of Net technology. Web 1.0 refers to the first generation of the commercial Internet, dominated by content that was only marginally interactive. Web 2.0, characterized by features such as tagging, social networks, and user-created taxonomies of content called "folksonomies," added a new layer of interactivity, represented by sites such as Flickr, Del.icio.us, and Wikipedia.

Analysts, researchers, and pundits have subsequently argued over what, if anything, would deserve to be called "3.0." Definitions have ranged from widespread mobile broadband access to a Web full of on-demand software services. A much-read article in the *New York Times* last November clarified the debate, however. In it, John Markoff defined Web 3.0 as a set of technologies that offer efficient new ways to help computers organize and draw conclusions from online data, and that definition has since dominated discussions at conferences, on blogs, and among entrepreneurs.

The 3.0 moniker has its critics. Miller himself, like many in his research community, frowns at the idea of applying old-fashioned software release numbers to a Web that evolves continually and on many fronts. Yet even skeptics acknowledge the advent of something qualitatively different. Early versions of technologies that meet Markoff's definition are being built into the new online TV service Joost. They've been used to organize Yahoo's food section and




make it more searchable. They're part of Oracle's latest, most powerful database suite, and Hewlett-Packard has produced open-source tools for creating Semantic Web applications. Massive scientific databases, such as the Creative Commons–affiliated Neurocommons, are being constructed around the new ideas, while entrepreneurs are readying a variety of tools for release this year.

The next wave of technologies might ultimately blend pared-down Semantic Web tools with Web 2.0's capacity for dynamic user-generated connections. It may include a dash of data mining, with computers automatically extracting patterns from the Net's hubbub of conversation. The technology will probably take years to fulfill its promise, but it will almost certainly make the Web easier to use.

"There is a clear understanding that there have to be better ways to connect the mass of data online and interrogate it," says Daniel Waterhouse, a partner at the venture capital firm 3i. Waterhouse calls himself skeptical of the "Web 3.0" hyperbole but has invested in at least one Semantic Web–based business, the U.K. company Garlik. "We're just at the start," he says. "What we can do with search today is very primitive."

Melvil Dewey and the Vision of a New Web

For more than a decade, Miller has been at the center of this slow-cresting technological wave. Other names have been more prominent—Web creator Tim Berners-Lee is the Semantic Web's most visible proselytizer, for example. But Miller's own experiences trace the technology's history, from academic halls through standards bodies and, finally, into the private sector.

In the often scruffy Web world, the 39-year-old Miller has been a clean-cut exception, an articulate and persuasive technological evangelist who looks less programmer than confident young diplomat. He's spent most of his professional life in Dublin, OH, far from Silicon Valley and from MIT, where he continues to serve as a research scientist. But it's no accident that Zepheira is based in this Columbus suburb, or that Miller himself has stayed put. Dublin is a hub of digital library science, and as the Semantic Web project has attempted to give order to the vast amounts of information online, it has naturally tapped the expertise of library researchers here.

Miller joined this community as a computer engineering student at Ohio State University, near the headquarters of a group called the Online Computer Library Center (OCLC). His initial attraction was simple: OCLC had the largest collection of computers in the vicinity of Ohio State. But it also oversees the venerable Dewey Decimal System, and its members are the modern-day inheritors of Melvil Dewey's obsession with organizing and accessing information.

Dewey was no technologist, but the libraries of his time were as poorly organized as today's Web. Books were often placed in simple alphabetical order, or even lined up by size. Libraries commonly numbered shelves and assigned books to them heedless of subject matter. As a 21-year-old librarian's assistant, Dewey found this system appalling: order, he believed, made for smoother access to information.

Dewey envisioned all human knowledge as falling along a spectrum whose order could be represented numerically. Even if arbitrary, his system gave context to library searches; when seeking a book on Greek history, for example, a researcher could be assured that other relevant texts would be nearby. A book's location on the shelves, relative to nearby books, itself aided scholars in their search for information.

As the Web gained ground in the early 1990s, it naturally drew the attention of Miller and the other latter-day Deweys at OCLC. Young as it was, the Web was already outgrowing attempts to categorize its contents. Portals like Yahoo forsook topic directories in favor of increasingly powerful search tools, but even these routinely produced irrelevant results.

Nor was it just librarians who worried about this disorder. Companies like Netscape and Microsoft wanted to lead their customers to websites more efficiently. Berners-Lee himself, in his original Web outlines, had described a way to add contextual information to hyperlinks, to offer computers clues about what would be on the other end.

This idea had been dropped in favor of the simple, one-size-fits-all hyperlink. But Berners-Lee didn't give it up altogether, and the idea of connecting data with links that *meant* something retained its appeal.

On the Road to Semantics

By the mid-1990s, the computing community as a whole was falling in love with the idea of metadata, a way of providing Web pages with computer-readable instructions or labels that would be invisible to human readers.

To use an old metaphor, imagine the Web as a highway system, with hyperlinks as connecting roads. The early Web offered road signs readable by humans but meaningless to computers. A human might understand that "FatFelines.com" referred to cats, or that a link led to a veterinarian's office, but computers, search engines, and software could not.

Metadata promised to add the missing signage. XML—the code underlying today's complicated websites, which describes how to find and display content—emerged as one powerful variety. But even XML can't serve as an ordering principle for the entire Web; it was designed to let Web developers label data with their own custom "tags"—as if different cities posted signs in related but mutually incomprehensible dialects.

In early 1996, researchers at the MIT-based World Wide Web Consortium (W3C) asked Miller, then an Ohio State graduate student and OCLC researcher, for his opinion on a different type of metadata proposal. The U.S. Congress was looking for ways to keep children from being exposed

to sexually explicit material online, and Web researchers had responded with a system of computer-readable labels identifying such content. The labels could be applied either by Web publishers or by ratings boards. Software could then use these labels to filter out objectionable content, if desired.

Miller, among others, saw larger possibilities. Why, he asked, limit the descriptive information associated with Web pages to their suitability for minors? If Web content was going to be labeled, why not use the same infrastructure to classify other information, like the price, subject, or title of a book for sale online? That kind of general-purpose metadata—which, unlike XML, would be consistent across sites—would be a boon to people, or computers, looking for things on the Web.

This idea resonated with other Web researchers, and in the late 1990s it began to bear fruit. Its first major result was the Resource Description Framework (RDF), a new system for locating and describing information whose specifications were published as a complete W3C recommendation in 1999. But over time, proponents of the idea became more ambitious and began looking to the artificial-intelligence community for ways to help computers independently understand and navigate through this web of metadata.

Since 1998, researchers at W3C, led by Berners-Lee, had been discussing the idea of a "semantic" Web, which not only would provide a way to classify individual bits of online data such as pictures, text, or database entries but would define relationships between classification categories as well. Dictionaries and thesauruses called "ontologies" would translate between different ways of describing the same types of data, such as "post code" and "zip code." All this would help computers start to interpret Web content more efficiently.

In this vision, the Web would take on aspects of a database, or a web of databases. Databases are good at providing simple answers to queries because their software understands the context of each entry. "One Main Street" is understood as an address, not just random text. Defining the context of online data just as clearly—labeling a *cat* as an *animal*, and a *veterinarian* as an *animal doctor*, for example—could result in a Web that computers could browse and understand much as humans do, researchers hoped.

To go back to the Web-as-highway metaphor, this might be analogous to creating detailed road signs that cars themselves could understand and upon which they could act. The signs might point out routes, describe road and traffic conditions, and offer detailed information about destinations. A car able to understand the signs could navigate efficiently to its destination, with minimal intervention by the driver.

In articles and talks, Berners-Lee and others began describing a future in which software agents would similarly skip across this "web of data," understand Web pages' metadata content, and complete tasks that take humans hours today. Say you'd had some lingering back pain: a program might determine a specialist's availability, check an insurance site's database for in-plan status, consult your calendar, and schedule an appointment. Another program might look up restaurant reviews, check a map database, cross-reference open table times with your calendar, and make a dinner reservation.

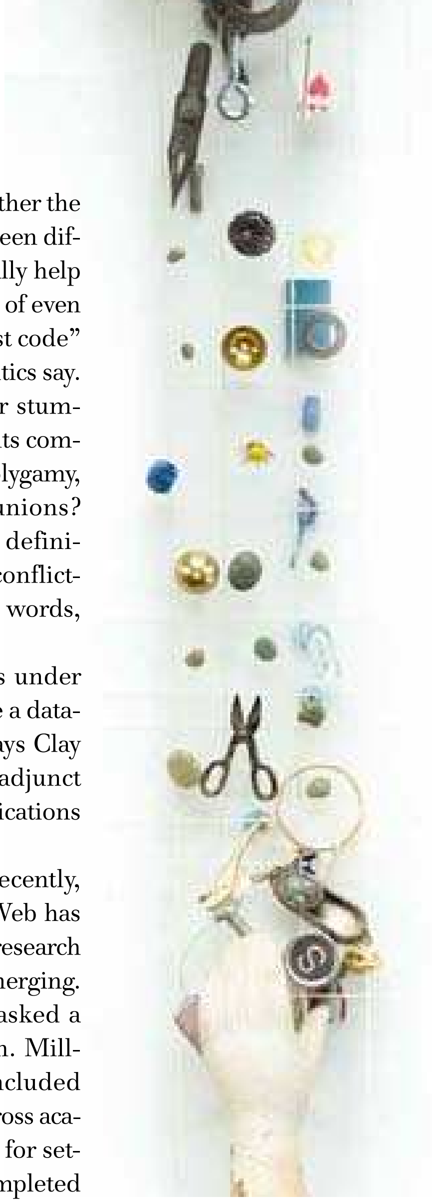
At the beginning of 2001, the effort to realize this vision became official. The W3C tapped Miller to head up a new Semantic Web initiative, unveiled at a conference early that year in Hong Kong. Miller couldn't be there in person; his wife was in labor with their first child, back in Dublin. Miller saw it as a double birthday.

This idea had been dropped in favor of the simple, one-size-fits-all hyperlink. But Berners-Lee didn't give it up altogether, and the idea of connecting data with links that *meant* something retained its appeal.

Standards and Critics

The next years weren't easy. Miller quickly had to become researcher, diplomat, and evangelist. The effort to build the Semantic Web has been well publicized, and Berners-Lee's name in particular has lent its success an air of near-inevitability. But its visibility has also made it the target of frequent, and often harsh, criticism.

Some argue that it's unrealistic to expect busy people and businesses to create enough metadata to make the Semantic Web work. The simple tagging used in Web 2.0 applications lets users spontaneously invent their own descriptions, which may or may not relate to anything else. Semantic Web systems require a more complicated infrastructure, in which developers order terms according to their conceptual relationships to one another and—like Dewey with his books—fit data into the resulting schema. Creating and maintaining these schemas, or even adapting preëxisting ones, is no trivial task. Coding a database or website with metadata in the language of a schema can itself be painstaking work. But the solution to this problem may simply be better tools for creating metadata, like the blog and social-networking sites that have made building personal websites easy. "A lot of Semantic Web researchers have realized this disconnect and are investing in more human interfaces," says David Huynh, an MIT student who has helped create several such tools.



Other critics have questioned whether the ontologies designed to translate between different data descriptions can realistically help computers understand the intricacies of even basic human concepts. Equating "post code" and "zip code" is easy enough, the critics say. But what happens when a computer stumbles on a word like "marriage," with its competing connotations of monogamy, polygamy, same-sex relationships, and civil unions? A system of interlocking computer definitions could not reliably capture the conflicting meanings of many such common words, the argument goes.

"People forget there are humans under the hood and try to treat the Web like a database instead of a social construct," says Clay Shirky, an Internet consultant and adjunct professor of interactive telecommunications at New York University.

It hasn't helped that until very recently, much of the work on the Semantic Web has been hidden inside big companies or research institutions, with few applications emerging. But that paucity of products has masked a growing amount of experimentation. Miller's W3C working group, which included researchers and technologists from across academia and industry, was responsible for setting the core standards, a process completed in early 2004. Like HP, other companies have also created software development tools based on these standards, while a growing number of independent researchers have applied them to complicated data sets.

Life scientists with vast stores of biological data have been especially interested. In a recent trial project at Massachusetts General Hospital and Harvard University, conducted in collaboration with Miller when he was still at the W3C, clinical data was encoded using Semantic Web techniques so that researchers could share it and search it more easily. The Neurocommons project is taking the same approach with genetic and biotech research papers. Funded by the scientific-data management company Teranode, the Neurocommons is again working closely with W3C, as well as with MIT's Computer Science and Artificial Intelligence Laboratory.

Government agencies have conducted similar trials, with the U.S. Defense Advanced Research Projects Agency (DARPA) investing heavily in its own research and prototype projects based on the Semantic Web standards. The agency's former Information Exploitation Office program manager Mark Greaves, who oversaw much of its Semantic Web work, remains an enthusiastic backer.

"What we're trying to do with the Semantic Web is build a digital Aristotle," says Greaves, now senior research program manager at Paul Allen's investment company, Vulcan, which is sponsoring a large-scale artificial-intelligence venture called Project Halo that will use Semantic Web data-representation techniques. "We want to take the Web and make it more like a database, make it a system that can answer questions, not just get a pile of documents that might hold an answer."

Into the Real World

If Miller's sunset epiphany showed him the path forward, the community he represented was following similar routes. All around him, ideas that germinated for years in labs and research papers are beginning to take root in the marketplace.

But they're also being savagely pruned. Businesses, even Miller's Zepheira, are adopting the simplest Semantic Web tools while putting aside the more ambitious ones. Entrepreneurs are blending Web 2.0 features with Semantic Web data-handling techniques. Indeed, if there is to be a Web 3.0, it is likely to include only a portion of the Semantic Web community's work, along with a healthy smattering of other technologies. "The thing being called Web 3.0 is an important subset of the Semantic Web vision," says Jim Hendler, professor of computer science at Rensselaer Polytechnic Institute, who was one of the initiative's pioneer theorists. "It's really a realization that a little bit of Semantic Web stuff with what's called Web 2.0 is a tremendously powerful technology."

Much of that technology is still invisible to consumers, as big companies internally apply the Semantic Web's efficient ways of organizing data. Miller's Zepheira, at least today, is focused on helping them with that job. Zepheira's pitch to companies is fairly simple, perhaps looking once again to Dewey's disorganized libraries. Businesses are awash in inaccessible data on intranets, in unconnected databases, even on employees' hard drives. For each of its clients, Zepheira aims to bring all that data into the light, code it using Semantic Web techniques, and connect it so that it becomes useful across the organization. In one case, that might mean linking Excel documents to payroll or customer databases, in another, connecting customer accounts to personalized information feeds. These disparate data sources would be tied together with RDF and other Semantic Web mechanisms that help computerized search tools find and filter information more efficiently.

One of the company's early clients is Citigroup. The banking giant's global head of capital markets and banking technology, Chris Augustin, is heading an initiative to use semantic technologies to organize and correlate information from diverse financial-data feeds. The goal is to help identify capital-market investment opportunities. "We are interested in providing our customers and traders with the latest information in the most relevant and timely manner to help them make the best decisions quickly," says Rachel Yager, the program director overseeing the effort.

Others are beginning to apply semantic techniques to consumer-focused businesses, varying widely in how deeply they draw from the Semantic Web's well.

The Los Altos, CA–based website RealTravel, created by chief executive Ken Leeder, AdForce founder Michael Tanne, and Semantic Web researcher Tom Gruber, offers an early example of what it will look like to mix Web 2.0 features like tagging and blogging with a semantic data-organization system. The U.K.-based Garlik, headed by former top executives of the British online bank Egg, uses an RDF-based database as part of a privacy service that keeps customers apprised of how much of their personal information is appearing online. "We think Garlik's technology gives them a really interesting technology advantage, but this is at a very early stage," says 3i's Waterhouse, whose venture firm helped fund Garlik. "Semantic technology is going to be a slow burn."

San Francisco–based Radar Networks, created by EarthWeb cofounder Nova Spivack and funded in part by Allen's Vulcan Capital, plans eventually to release a full development platform for commercial Semantic Web applications, and will begin to release collaboration and information-sharing tools based on the techniques this year. Spivack himself has been part of the Semantic Web community for years, most recently working with DARPA and SRI International on a long-term project called CALO (Cognitive Agent that Learns and Organizes), which aims to help military analysts filter and analyze new data.

Radar Networks' tools will be based on familiar ideas such as sharing bookmarks, notes, and documents, but Spivack says that ordering and linking this data within the basic Semantic Web framework will help teams analyze their work more efficiently. He predicts that the mainstream Web will spend years assimilating these basic organization processes, using RDF and related tools, while the Semantic Web's more ambitious artificial-intelligence applications wait in the wings.

"First comes what I call the World Wide Database, making data accessible through queries, with no AI involved," Spivack says. "Step two is the intelligent Web, enabling software to process information more intelligently. That's what we're working on."

One of the highest-profile deployments of Semantic Web technology is courtesy of Joost, the closely watched Internet television startup formed by the creators of Skype and Kazaa. The company has moved extraordinarily quickly from last year's original conception, through software development and Byzantine negotiations with video content owners, into beta-testing of its customizable peer-to-peer TV software.

That would have been impossible if not for the Semantic Web's RDF techniques, which Joost chief technology officer Dirk-Willem van Gulik calls "XML on steroids." RDF allowed developers to write software without worrying about widely varying content-use restrictions or national regulations, all of which could be accommodated afterwards using RDF's Semantic Web linkages.

Joost's RDF infrastructure also means that users will have wide-ranging control over the service, van Gulik adds. People will be able to program their own virtual TV networks—if an advertiser wants its own "channel," say, or an environmental group wants to bring topical content to its members—by using the powerful search and filtering capacity inherent in the semantic ordering of data.

But van Gulik's admiration goes only so far. While he believes that the simpler elements of the Semantic Web will be essential to a huge range of online businesses, the rest he can do without. "RDF [and the other rudimentary semantic technologies] solve meaningful problems, and it costs less than any other approach would," he says. "The entire remainder"—the more ambitious work with ontologies and artificial intelligence—"is completely academic."

A Hybrid 3.0

Even as Semantic Web tools begin to reach the market, so do similar techniques developed outside Miller's community. There are many ways, the market seems to be saying, to make the Web give ever better answers.

Semantic Web technologies add order to data from the outset, putting up the road signs that let computers understand what they're reading. But many researchers note that much of the Web lacks such signs and probably always will. Computer scientists call this data "unstructured."

Much research has focused on helping computers extract answers from this unstructured data, and the results may ultimately complement Semantic Web techniques. Data-mining companies have long worked with intelligence agencies to find patterns in chaotic streams of information and are now turning to commercial applications. IBM already offers a service that combs blogs, message boards, and newsgroups for discussions of clients' products and draws conclusions about trends, without the help of metadata's signposts.

"We don't expect everyone to go through the massive effort of using Semantic Web tools," says Maria Azua, vice president of technology and innovation at IBM. "If you have time and effort to do it, do it. But we can't wait for everyone to do it, or we'll never have this additional information."

An intriguing, if stealthy, company called Metaweb Technologies, spun out of Applied Minds by parallel-computing pioneer Danny Hillis, is promising to "extract ordered knowledge out of the information chaos that is the current Internet," according to its website. Hillis has previously written about a "Knowledge Web" with data-organization characteristics similar to those that Berners-Lee champions, but he has not yet said whether Metaweb will be based on Semantic Web standards. The company has been funded by Benchmark Capital, Millennium Technology Ventures, and eBay founder Pierre Omidyar, among others.

"We've built up a set of powerful tools and utilities and initiatives in the Web-based community, and to leverage and harness them, an infrastructure is desperately needed," says Millennium managing partner Dan Burstein. "The Web needs extreme computer science to support these applications."

Alternatively, the socially networked, tag-rich services of Flickr, Last.fm, Del.icio.us, and the like are already imposing a grassroots order on collections of photos, music databases, and Web pages. Allowing Web users to draw their own connections, creating, sharing, and modifying their own systems of organization, provides data with structure that is usefully modeled on the way people think, advocates say.

"The world is not like a set of shelves, nor is it like a database," says NYU's Shirky. "We see this over and over with tags, where we have an actual picture of the human brain classifying information."

No one knows what organizational technique will ultimately prevail. But what's increasingly clear is that different kinds of order, and a variety of ways to unearth data and reuse it in new applications, are coming to the Web. There will be no Dewey here, no one system that arranges all the world's digital data in a single framework.

Even in his role as digital librarian, as custodian of the Semantic Web's development, Miller thinks this variety is good. It's been one of the goals from the beginning, he says. If there is indeed a Web 3.0, or even just a 2.1, it will be a hybrid, spun from a number of technological threads, all helping to make data more accessible and more useful.

"It's exciting to see Web 2.0 and social software come on line, but I find it even more exciting when that data can be shared," Miller says. "This notion of trying to recombine the data together, and driving new kinds of data, is really at the heart of what we've been focusing on." TR

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Fiction

Osama Phone Home

By David Marusek
Illustrations by Istvan Banyai

We arrived by rental car and parked next to a delivery van in the lot closest to the freeway on-ramp. The van hid us from the security cam atop a nearby light pole. We were early, traffic being lighter than expected. As we waited, we touched up our disguises. ¶ At 09:55, we left the car singly and proceeded to our target site by separate mall entrances. I rode the escalators to the food court on the third level, while G, C, and B quickly reconned the lower floors, where shops were just opening their grates.

I started at the burger stand and ordered a breakfast sandwich. The girl behind the counter was pretty, mid-20s, talking on her cell. She snapped it shut and asked, without making eye contact, if I wanted something to drink with that. She looked as if she'd been crying. I said no thanks, and she rang up and assembled my order. As she did so, I ticked off the mental checklist we had memorized: slurring of speech—negative; loss of balance or coördination—negative. About two dozen data points in all.

When my receipt printed out, she tore it off with a deft flick of her wrist and glanced up at me. Apparently that was all it took, because she said, "I'm only working here to kill my mother."

I made no reply, as per instructions, and fresh tears welled in her eyes. "Oh, it's true!" she declared. "I'm a spiteful daughter who only lives to torment her mother. I admit it! I have a freakin' master's degree in marketing from NYU, and I was a founding owner of Toodle-Do.biz. I practically *ran* Toodle-Do from my bedroom. Sixteen hours a day! But did she care? No! She was all, 'Why don't you find a *real* job?' She couldn't even comprehend what Toodle-Do was. I mean, I could tie her to a chair and put a fucking laptop in her fucking lap and use her own finger to point at the screen, and *still* she can't see it. I mean, what do I have to do?"

Once she was rolling, the young woman's confession built up momentum and volume, and her coworkers glanced nervously at us. "I'll tell you what I did! I sold my shares in Toodle-Do and took the most demeaning, most mindless 'real job' I could find!" She gestured to take in the whole burger stand. "See that?" She pointed at the deep-fat fryers, where a pimply boy was racking baskets of fries. "I stand next to *boiling grease* all day. When I go home, I don't even have to open my mouth. No way! It's in my hair. It's in my clothes. It's in my *skin*." She raised both wrists to her nose and inhaled. "I smell like a freakin' *exhaust fan*, and it *drives her mad!* Oh, it pushes her *right over the edge!* My grandmother died of a stroke when she was only in her *50s*, and every night I pray to *God* to give my mother one too!"

She went on like this, and the fries boy came over to add masturbatory sins of his own, but I'd heard enough and took my egg sandwich to the seating area. I spied a middle-aged man in a rumpled suit talking on a cell phone. He had a cup of coffee, so I went over to sit near him. He was so engrossed in his conversation that he didn't notice me eavesdropping.

"Uh-huh … uh-huh," he said while pushing doughnut crumbs around the tabletop with his finger. "The reason I called … uh-huh … the reason I called … uh-huh." He took a final sip of coffee and said, "Listen, Ted, shut up for a minute, will you? I have something important to say. Yeah … that's right. You're my brother, and I love you, but I've been holding this back for too long. Uh-huh … You know Billy? Yeah, your kid, Billy, only he's"—the man wiped his brow with a paper napkin—"he's not your son. He's your *nephew*."


LADEN
& Co.
Beee...eeeee

There was a long pause, and then the man continued, "What the *hell* do I mean? I'll tell you what the *hell* I mean." And he did so, in excruciating detail. I half listened as I checked off my list: muscle twitching—negative; bizarre behavior—negative. Out of the corner of my eye I watched G, C, and B working the other tables, approaching anyone drinking coffee from one of our vendors.

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We compared notes on the drive back to the motel. Beyond a doubt, True Confessions was a keeper. The early reports on its harmlessness seemed justified. Nevertheless, C's idea of delivering test doses via adulterated coffee was a brilliant precaution, because no children became involved. We're patriots, not monsters.

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M's part in the operation had concluded that morning, and when we arrived at the motel room, she was in the bathroom removing tattoos. We quickly changed our clothes and cleaned the room for final departure, meanwhile logging our test results. M came out of the bathroom a new brunette with scrubbed pink arms, and B and G went in to remove their disguises. M walked around the room gathering up her things and asking how it all went. C looked up from his handset long enough to say, "It's true! No offense is too large or too small for a detailed accounting."

M nodded thoughtfully, then turned to me and said, "And this is a good thing, why?"

I just grinned, and she let it drop, said she had to go get her kid, and left.

G, meanwhile, was in the bathroom brewing up a celebratory pot of coffee. His idea of a joke.

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Six years ago, in March 2002, I happened to attend a barbecue in the backyard of some good friends. As the flesh sizzled on the grill, we attempted small talk to pass the time, as we usually did. But in those early months, feelings were still too raw for small talk.

Fortunately, there was beer.

Someone had read an article—"The Battle of the Organizational Charts"—comparing the relative efficacies of a classical top-down hierarchy like General Motors and a distributed network like al-Qaeda. Apparently, the term "al-Qaeda" means "the database" in Arabic and was coined in the 1980s, when we were fielding freedom fighters in our Afghan proxy war against the Soviets. Not an operational organization itself, al-Qaeda is a sort of "Ford Foundation for jihadist startups," as a pundit put it, that provides support in the form of financing, expertise, and coördination. In an "ah-ha moment," one of us, with a mouth full of pulled pork, bragged that our old college crowd could form such an organization. Even better—because we weren't limited to box-cutter technology, we could out-qaeda al-Qaeda.

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It was a beer-soaked boast, soon forgotten. But not a week later, the president of the United States held a news conference at the White House. When reporters asked him about Osama bin Laden, who had recently escaped capture by our troops in Afghanistan, he said, "I truly am not that concerned about him."

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In all honesty, this presidential statement floored me. Not concerned about bin Laden? How could our president not be concerned about him? Was there anything our government could have found to say to the American people that day more knuckleheaded than this?

A few of my friends gathered again, this time stone sober. We played one of bin Laden's videotaped sermons to the West. This lunatic with a Kalashnikov, wagging his finger at our whole culture, had somehow slipped through our military's grasp at Tora Bora. We should have had him—but we didn't. And then—according to the president—he and his whole murderous crew dropped off our radar altogether?

That didn't sit well with my friends and me, but we weren't sure what to make of it. The news-conference dismissal might have been nothing more than our president's sometimes difficult way with words. Or his inability to admit to failure. But we didn't think so. Most likely it was the president's way of admitting that the hunt for bin Laden had gotten lost in the shuffle on the road to war in Iraq. It made us wonder if there wasn't a place for private citizens in the war on terror. Perhaps we could lend a hand.

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An affinity group can form around any mutual interest: tasting Beaujolais wines, singing in a choir, attending a communal sauna. We called our group the American Curling Club. We are a small group of men and women who roomed and/or socialized together in college back in the day. We came from middle-class families and attended a prestigious, but not Ivy League, school. There wasn't a legacy among us. We pretty much put ourselves through school with student loans, scholarships and grants, parental handouts, and part-time jobs.

After graduation, we went our separate ways but kept in touch. We attended each other's weddings, and we are watching each other's kids grow up. We have built comfortable lives. We have climbed to upper-management positions in our chosen fields.

We firmly believe in freedom and free markets. We are Christians, or at least most of us are. We're your average janes and joes with no particular ax to grind, except this one—Osama bin Laden must pay *in full measure* for what he has done.

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The American Curling Club formed in order to play a key role in bringing bin Laden to justice: namely, to locate him. It seemed to us to be an important and doable project. If our government couldn't or wouldn't find him, we would. And when we found him, if only his grave, we would forward his coördinates to the relevant agencies. We would do this as a public service, not for the $25 million State Department bounty on him.

Though our mission was lawful, we realized that pursuing it might require us to bend a few rules and make a few enemies. So we pledged our own lives and liberty to each other and swore an oath of secrecy. We established appropriate security protocols to shield the ACC core group.

Collectively, we had expertise in a number of fields, including telecommunications, biochemistry, the military, civil government, and finance, but our contacts extended far into other areas. Each of us was charged with organizing further assets—networked cells and task groups—behind strong firewalls. Initially we chipped in our own savings to bootstrap our enterprise, but eventually our swifty cells became adept at targeting bank transfers in large offshore money-laundering operations. Soon we were able to finance ourselves by imposing "sin taxes" on drug cartels and playboy dictators. To name a few.

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In the summer and fall of 2002, while we were recruiting our go-to, wizard, swifty, lineman, and expat cells, we met frequently to bat around ideas for achieving mission success. Because truly brilliant ideas can sound crazy at first, and because committees smother ideas, we declared that during our freewheeling brainstorming sessions no idea was too outrageous to say out loud.

What if we invented a surrender dust, keyed to bin Laden's DNA?

Or what about informer dust storms?

Our powers of imagination were running a bit hot in those days. What with all the news of war and rumors of war. What with the anthrax, Saddam, and the shoe bomber who ruined air travel forever.

What if we embedded artificial memories in people throughout the Middle East so that they were certain they remembered Osama mocking the Prophet in public?

What if we afflicted all adult males taller than six foot three in the tribal regions of Pakistan with the mother of all tooth abscesses, requiring immediate dental surgery in Peshawar, and then watched the dentists?

With righteous fervor, in sessions that lasted through the night, we loosed the dogs of ingenuity upon the Sheikh of Saudi Arabia.

What if we made the mountains of eastern Afghanistan begin to hum? An unrelenting low-frequency thrumming that seemed to rise from the very rocks and that drove people out into open spaces screaming and tearing their hair?

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My own résumé nominated me to form and coördinate our go-to cells, including an elite cell that I headed myself. Among my first recruits were several Desert Storm vets whose toughness and loyalty were known to me. They, in turn, helped me do background checks and interviews to fill out their own cells.

People claim that this nation of ours is too polarized, that we hardly recognize the other half that doesn't think as we do. But I'm here to say there's one issue that all Americans can agree on, no matter where they stand on most everything else: our nation won't rest until Osama bin Laden faces justice. This truth alone was our most effective recruitment tool. We characterized the ACC as an off-the-books government black op with one simple mission. The fact that we paid well, and in cash, helped, too.

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Eventually it was time to tether our brainstorming to reality. Our wizard cells were up and running, and we passed them our favorite ideas for critical feedback. They, in turn, fed us weekly "News-to-Use" summaries of developments across a broad range of fields. Our brilliant ideas became somewhat tempered by scientific reality.

For instance, geneticists are cultivating plants that grow medicines in their leaves and fruit. They already have a potato rabies vaccine and a tomato HIV drug. Transgenic tobacco plants alone produce dozens of "farmaceuticals," everything from human growth hormone to cancer drugs.

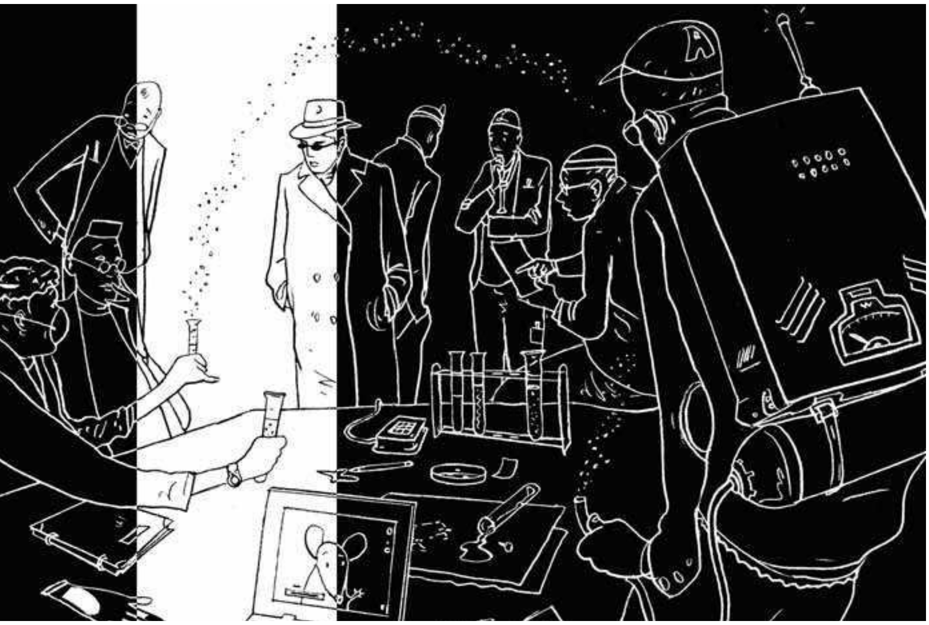
What if we engineered a hybrid tomato or lettuce crop that contained a therapeutic dose of Xanax or Prozac and introduced it to the Middle East? Could that help reduce the bloodshed? Seriously, treat a whole region like a patient.

Or: Does Osama use sunscreen? For decades, sunscreen was whitish and opaque because of the properties of one of its chief ingredients, zinc oxide. In the 1990s, researchers found that if they made the zinc oxide mole-

cules really tiny, they could produce a much more pleasing clear sunscreen. It was one of the first commercial successes of nanotechnology, and the source of the first nanotech-related product liability lawsuits.

The problem was that nanoparticles are so small they pass through the skin and enter the bloodstream. They even cross the blood-brain barrier and come to rest, like shells on a beach, in the sun worshiper's brain.

Researchers wondered if nanoparticles could be designed to collect in other kinds of tissue—feathers, for instance. That's what one radar ornithology group is attempting to find out in an avian-flu-related study for the DoI. They are sizing and shaping nanoparticles of various materials to pass through the birds' skin and collect in developing feathers. Their ultimate goal is to nanobrand entire flocks of birds on the wing for precise tracking across the globe by radar.



What if we found nanoparticles that collect in hair and beards instead? Our flocks would be the occupants of jihadist camps, caves, and villages. We could detect and track them remotely.

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While the core group was still wrastling the angels of inspiration, my go-to cells were employed in preliminary logistical tasks: establishing safe houses, moving cash, rounding up supplies for the wizard cells. In this latter effort, C came to the fore with his experience in corporate R&D. We purchased several whole laboratories' worth of gear and dropped it in self-storage units on both coasts. Because the ACC had rightly ruled out the use of germs or bombs (we're patriots, not terrorists), we weren't trafficking in restricted material per se. But lately our government has taken to quietly monitoring sales of even innocuous gear like beakers and pipettes, and we took great pains to leave no trail.

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We knew from the start that one of the ACC's strengths was its position in the telecom industry, and we soon realized that Uncle Sam had provided us an easy leg up in prosecuting our mission.

Al-Qaeda is notorious for passing communication by hand in order to circumvent electronic surveillance. One reason for this has to do with bin Laden's own personal experience in the 1990s. According to news accounts at the time, Osama bin Laden really liked talking on his Inmarsat satellite phone. He especially enjoyed calling his mother in Saudi Arabia from his Afghan camps. We know this because the NSA was listening in on their conversations from at least 1996. This happy arrangement, along with Osama's charming naïveté, came to an abrupt halt one day in August 1998, when he phoned his mother and told her he wouldn't be able to call "for a while." After hanging up, he turned off his sat phone. The next day, the president of the United States ordered a cruise missile strike on the phone's last known coördinates. We blew up a desert training camp that day, but the Dark Prince had already flown.

Is it any wonder that bin Laden became phone-shy after that? Most reasonable people would. At some point, the NSA decided that if it could no longer tap bin Laden's phone, the next best thing to do was tap everyone else's. This was actually not a bad idea, but it required compliant telecom companies to shunt complex spur lines into secret listening posts, often small rooms inside switching stations, where NSA spooks could sift billions of calls through their voodoo supercomputers. In creating this system, the NSA had done the heavy lifting for us, and our linemen inside the same telecoms tapped their taps. Soon we were channeling the same floodwaters of chatter, and we set our wizards trolling for keywords and casting social nets.

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I made it a point to become acquainted with the members of my go-to cells and their families, usually without anyone's knowledge. I confirmed that we had recruited outstanding individuals. Smart, gutsy, none of your house-in-the-burbs, corporate-treadmill types.

These were the cutups in middle school, the teenage pregnancies, the try-everything-once crowd. A little older now, a little more God-fearing and respectful of real realities. Solid.

After the initial flurry of organization, I kept these folks busy every other weekend or so (kinda like it used to be for the national guard). I kept my own elite group busier, if only with training exercises, several days or nights a week. Before long we were a pretty tight unit.

I had already worked with G, and he introduced me to C. And when I first recruited B, she told me about M, with whom she had served two tours. M was trained to pilot UAV combat drones, but lately she was back at home styling hair and raising a kid.

M had three kids, actually, but the older two had lived with their granny since they were born. Only the baby, a spoiled eight-year-old, lived with M. I found the kid hard to fool, but easy to bribe.

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In late 2002, one of our wizards presented us with a tantalizing what-if. He owned a startup that had developed a gobsmackingly elegant algorithm for creating and identifying pretty good voiceprints from poor-quality audio. It processed voices acoustically with no regard to the language spoken and no use of keyword recognition.

What if we trained all the phones in the world to recognize bin Laden's voice? His and his people's. And whenever a phone anywhere recognized one of these voices speaking into it, it would discreetly send us a text message with its GPS coördinates and call details. And what if phones could be trained to do this remotely by a phone virus? Voiceprint libraries could be updated automatically. It looked as if we had finally found our 21st-century Yankee box cutter.

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Because of the firewalls we had set in place, I learned who was in other cells and groups only on a need-to-know basis. Some of our groups included young people at the beginning of their careers. Like young people everywhere, they sometimes let their issues get in the way of their work. On occasion, my team was directed to remind individuals of the confidential nature of our mission. One such action involved a young computer genius in the Pacific Northwest. I sent M out there to investigate (Granny taking the kid temporarily). She reported back a few days later that the genius was a fool for pillow talk. To hear him speak, he was practically in charge of a counterterror task force. M also reported that the *real* loves of his life were his two Jack Russell terriers.

So I sent G up there to tutor the kid in the art of discretion. G did a Godfather on the pooches, and genius boy woke up the next morning with two little surprised expressions lying on the pillow next to him. End of bulletproof youth.

When M returned, she was very upset. She asked if that had really been necessary. Couldn't G have simply dognapped them for a few days to make a point? I said I would talk to him about it.

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In early 2003, our weekly "News-to-Use" included three disparate bits of intel that, when put together, made an intriguing picture: (1) Pakistanis in the tribal regions were sneezing; (2) a 60-year-old DoD skunk works project had borne fruit; and (3) dandelions can make you high.

(1) *Ambrosia*, commonly known as ragweed and native to North and South America, hitched a ride to Europe in the 19th century. The joy of hay fever has been spreading across Europe ever since. Apparently, the winds of recent wars have carried ragweed farther east, where it has found a suitable niche in the valley ecosystems of northern Pakistan bordering Afghanistan. It's been found in Waziristan province as well, and as far south as Quetta. We requested specimens and seeds from an expat cell, and what we received seemed to be a cross between *A. artemisiifolia*, the most widespread species in North America, and *A. dumosa*, one that thrives in the Sonoran Desert. The Pakistani species was said to be a particularly noxious weed that pumped out clouds of pollen.

(2) Since World War I, the U.S. Army's Edgewood Arsenal and its successor unit have explored the use of chemicals in warfare, conducting open-air nerve-gas tests in Maryland and even dosing unsuspecting soldiers with superhallucinogens. Their perennial hobbyhorse has been a reliable truth serum, or at least one better than the problematic sodium pentothal. In recent decades much of the unit's preliminary work has been outsourced to civilian researchers. In 2003, there was buzz of a breakthrough: MDMOEP, a phenethylamine compound and kissing cousin of MDMA (or ecstasy). Dubbed True Confessions, it was said to induce a state of abject self-reproach. Subjects were anxious to unburden themselves of their life's misdeeds, and they actively sought out receptive listeners, including parties they might have injured. The drug was tested on volunteers and was said to be safe, with no lasting side effects. What a boon to the war on terror! If only it had been ready in time to avert the Abu Ghraib mess. In any case, the U.S. Army Chemical Corps swooped down on the private lab that had made the discovery, confiscated all records, and reminded all involved of the Patriot Act.

(3) A brilliant young geneticist on the West Coast was doing groundbreaking work in biopharmaceuticals, especially in the mechanics of directing what part of the plant would store the finished drug—leaf, root, seed, or fruit.

Moreover, according to our private sources, this same professor was also conducting a little biopharma project outside the purview of his university department. He was attempting to genetically modify the common dandelion to produce the marijuana cannabinoid THC. According to our report, once his stoner dandelion was perfected, the professor intended to take a sabbatical in order to scatter little parachute seeds of Mellow Yellow along roadways all over the temperate zone.

What galvanized us about these three items was the observation that both ragweed and dandelion are members of the same Asteraceae family. It made us wonder. It definitely got the wheels turning.

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Development of our Yankee "vox cutter" proceeded quickly. The phone virus was coming along, and we had a SIMM chip in the works. However, we realized that even if we trained a million strategically located phone slaves to call us whenever they heard Osama's voice, or any voice in our voiceprint library, what good would that do us if Laden & Co. never lifted a receiver? We needed something to drive al-Qaeda to a phone. What we needed was a special friends-and-family calling plan for them, and we wondered if the army's new guilt serum might do the trick.

Not that we imagined for a moment that bin Laden felt any guilt or remorse over murdering three thousand Americans. But a crime doesn't have to be an atrocity to stimulate the TC effect: everyday misdemeanors might do, like shorting waiters or telling off-color jokes. Bin Laden is human and not an angel, and he must regret *something* he has done. He does have four wives, after all. And what about his 53 brothers and sisters and innumerable nephews and nieces? Just how many weddings and funerals did he have to miss while hiding in a cave? He inherited $80 million from his father and quickly turned it into $250 million. Even if that kind of return was earned honestly, how to explain to his 24 children that Daddy blew it all on jihad? And how to explain to them his thing for Whitney Houston?

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We set things in motion. First off was sizing up the deposed skunk works PI on the True Confessions project. I sent M and C up there to see if he wasn't suffering a case of defense-contractor hangover. He proved to be unapproachable, but one of his researchers had full-blown civil-liberties remorse. She had been caching her lab notes from the start and was trying to decide whether or not to post them anonymously on the Internet (as if that might absolve her). She was only too glad to turn them over to us—Amnesty International.

Before we could proceed any further, we had to test the drug ourselves in a real-world situation. There was no open or ethical way to do this, but at least we could do it in a controlled setting. So our wizards mixed up a test batch of TC, and my team performed our shopping-mall field trial. TC lived up to its billing, and the fact was not lost on us that many of our subjects turned to their cell phones for impromptu confessionals.

Next was enlisting Professor Mellow Yellow. I wanted to soften him up first, so I sent G and C to his university office posing as DEA agents to scare the bejesus out of him. I was waiting for him in his home greenhouse when he showed up an hour later. I was sitting on a stool next to a potting bench that held trays of dandelions. Some of the cheery yellow flowers were sugar-frosted with sticky cannabis resin. I introduced myself as Mr. Homeland Security and told him about all the kinds of trouble he was in. Then, in true TV cop-show fashion, I offered to call off the drug dicks if he volunteered to serve his country in a very important mission. As it turned out, Prof. Mellow was so enthused by our mission and the sheer complexity of his part in it that I almost regretted siccing the DEA crew on him.

I turned Prof. Mellow over to one of our wizard handlers and later learned that we set him up in a special complex of greenhouses, ostensibly doing research on new allergy meds for major pharma.

In order to spread our voiceprint traps, the ACC set up several NGOs to integrate vox-cutter tech into the public-call-office landline systems in Pakistani villages and to subsidize the extension of cell coverage in remote areas. Back at home, we sent go-tos on shopping trips to stockpile cheap prepaid cell phones. We made cash purchases of handsets at every Wal-Mart and Radio Shack across America. We shipped boxloads of them to linemen who replaced their chips with our own vox-cutter SIMMs and bundled them for distribution with hand-crank chargers.

Our wizards were keeping tabs on the town where we staged our shopping-center test. We were monitoring for any possible fallout or aftereffects, such as a change in homicide, suicide, or domestic-violence rates. The only aftereffect we detected was the linger-

ing spell M seemed to have cast on the coffee wholesaler whose stock we had adulterated. Shortly after the test, he phoned his sister in Texas and told her about a woman he'd met on a recent Sunday after church. They had hit it off in a big way. She had a precocious little girl who after only two days was calling him Uncle Duane. Uncle Duane was perplexed when all of a sudden his two special girls left town without so much as a good-bye, and he wondered if they were in any kind of trouble.

A year later he continued to wonder, in rambling weekly calls to his sister. And I was unhappy with M about involving her kid in an operation.

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Time passed, and Project Phone Home burbled along. Prof. Mellow was making great strides in realizing two of our requirements for *Ambrosia osamum*. First, the drug was to accumulate not in the ragweed leaf or flower but on the surface of its pollen, where it could be readily absorbed by the mucous membranes of the eyes and nose. Second, the TC genes were to be expressed only in the first generation of ragweed plants. After that they turned themselves off. The last thing we wanted was for this guiltweed to get away from us and spread to wild plants. Unlike Prof. Mellow with his pet dandelions, the ACC is opposed to letting GM Frankensteins loose. We're patriots, not God.

When the time came for human trials, the prof rounded up volunteers among the greenhouse workers. The results were positive: red, runny noses; itchy eyes; and inflamed consciences.

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Then some bad news arrived to spoil the mood. The civilian researchers from the army TC project were being called in for lengthy interviews. We felt pretty confident about our contact, since her neck was on the same block as ours. But there was the possibility the army might interview her with the help of the drug itself. M and C had become compromised.

On top of that, Uncle Duane was still obsessing about M. By now she and the kid were the lost loves of his life, and he posted photos of them on Flickr and on sites for missing and exploited children. Worse, his sister in Texas had persuaded him to hire a detective, for his own peace of mind.

It was only a matter of time before Duane and the army bumped into each other, so in accordance with ACC firewall protocol, the core group ordered me to contain the damage. With prejudice, if necessary. I thought long and hard about how best to accomplish this. We could hardly strong-arm Uncle Duane at that point, and we sure couldn't stop the army. Seeing no alternative, with or without prejudice, I called my go-to team together and broke the bad news. M was off the team, permanently. She should never have involved the kid. I told them that at the conclusion of the meeting, I would be escorting M and daughter to a safe house, where a relocation specialist would pick them up. M was to have cosmetic surgery and, just as important, a voice change. The ACC would cover all costs, including a monthly stipend. And a cash bonus when the bastard was captured or killed. But there would be no further contact between her and any of us, ever. B took it the worst, but the whole team was troubled. M said she knew she had screwed up royal but didn't want to put her daughter through a life on the run and asked if she could leave her with Granny. I said that was probably not such a hot idea, since the kid could ID us all. Besides, if she left her kid she would be miserable, and the kid would be miserable. In the end, my reasoning prevailed, and M and the team made their last farewells. M's parting words were "I'm gonna watch the news every night, and when we win, I'm going to raise a glass to all of you. God bless and good-bye."

I drove M to pick up the kid, then to their place to pack, and then on to the first leg of their brave new life.

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During the next two years, work on Project Phone Home proceeded smoothly. There were no further signs of the army or anyone else on our tail. Meanwhile, the ACC developed several backup plans for locating bin Laden, and my go-tos were engaged in implementing them.

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Seed day. We made final prep for handing off the GM ragweed to an expat in time for spring sowing in the lush valleys of northwest Pakistan. Six hundred hermetically sealed bags, 50 pounds each, of washed seed. I had sent C to the greenhouses to guarantee a pollen-free shipment. Some deluded soul over there, possibly Prof. Mellow high on dandelions, had plastered the shipping pallets with "Clinton in '08" stickers.

Our immediate task was to double-bag the shipment in USAID-imprinted gunnysacks and transship it to a dummy agri-coöp in Peshawar as high-yield rye seed, which it resembled. Taking no chances, I had linemen rig up an industrial HEPA-filtered ventilation hood in the warehouse for us to work under. And I made my crew wear full hazmat gear. It was heavy work, and despite the January night and unheated warehouse, we fogged up our face masks with the effort.

We finished at dawn, and after cleaning up and disposing of used filters, I sent the crew home. B and G waited with me for the freight company to pick up the seeds and a final pallet of phones, and then we went to an IHOP for breakfast.

We were in a celebratory mood; this marked the completion of our part in the vox-cutter project. From then on its success was up to strangers. We wolfed down a breakfast of cakes, eggs, and sausages. We proposed toasts with orange juice and coffee. G toasted to Operation Ragweed for Ragheads. B toasted to M and her kid, wherever they were and whoever they had become.

When the waitress came over with more coffee, she said, "I know it's petty of me and wrong, but I resent happy people like you." She spoke calmly, refilled our cups, and went away.

We gaped at each other. I stood up to peer over the booth partitions and saw patrons crying into their phones. We left immediately. The woman at the register told us how sometimes she pilfered from the tip jar. Her eyes and nose were not inflamed, so whatever vector was involved in dispersing the TC, it wasn't our pollen. On the sidewalk outside, a guy on a mountain bike and a woman with a shopping cart were trying to unburden themselves to each other. So it probably wasn't the coffee or restaurant food either. In fact, all up and down the street we saw penitents fessing up to one another.

G craned his neck and peered into the sky. "Aerial spraying?" he said. "An area-wide dragnet?" We wondered if we were the target. But we didn't stick around to find out.

A woman was slumped against the bumper of our car. She looked at us and said, "Is this all I get?" I helped her to her feet. "I mean, I know I'm ugly. I've known that since I was a child, but does it mean my life has to be so small and empty and meaningless?"

I turned her toward the intersection and told her to find a taxi and go home. And if she had a phone, to use it.

We jumped into the car, G behind the wheel. "Where to?" he yelled, pulling into traffic.

I told him to drive back to the warehouse. No matter how the TC was being dispersed, our hazmat gear there had protected us. My plan was for us to suit up before evacuating the area. Then my phone rang, a call from C. I asked him where he was.

He said, "I feel like telling you that 10 years ago I acquired a complete microfiche set of engineering plans for the Trans-Alaska Pipeline."

"I don't care about that. Where are you?"

"At the warehouse. Listen, I sold the plans for a shitload of money. You want to know who to?"

I ordered him to destroy his phone and stay put till someone came for him. Then I hung up and told G to forget the warehouse and head for the bridge instead. He made a sharp U-turn and nearly hit an SUV. He had to brake so hard he stalled the engine. But instead of restarting it, he just sat there staring out the windshield. In the back seat, B said, "They showed us color photos of aborted fetuses. They said a baby as old as mine already had perfect little fingernails."

I ordered her to shut up and Gus to drive, but he turned around in his seat and said, "I saw my father kill my mother, and I lied to the police about it."

"Drive! Drive!"

"I was only five years old. He made it out to look like an accident, but he never fooled me."

I ordered them to hand over their cell phones, but Bella dialed a number, and as it rang she told us, "And perfect little eyelashes." When her party answered, she began to weep.

"Stop crying!" I barked at her. But she didn't stop, and Gus joined her. A sight to behold—Gus Ostermann pressing the heels of his hands against his temples. "All the poor dogs!" he cried. "And all the poor cats."

We sat there for a long time, traffic piling up and passing around us as we talked to the people we loved. Before army intelligence arrived, I received a text message from the ACC. A single word, backed by the authority of the core group—"JUG." Short for jugulate, which was what they were directing me to do in order to protect the ACC. I couldn't allow us to be taken alive, that much was clear. I have sworn an oath to lay down my life for the group, and I will, only not right now. Right now I actually feel like answering a few questions.

My name is William B. Boothtipple. My number is 973-555-0979. If it's busy, leave voice mail or keep trying; no doubt I'm on the other line spilling my guts.

And now some shout-outs:

—To Melody and her awesome kid, Kimmie, wherever you are and whoever you've become. Duane wasn't the only one you bewitched; I think of you guys all the time. If I had known how much I'd miss you, I would never have let you go.

—To Osama. Hey, man, seriously, phone home. It's been years since they've heard your voice, and everyone's worried sick. TR

David Marusek lives in Fairbanks, AK, where he is working on the sequel to his first novel, Counting Heads. *His collection of stories,* Getting to Know You, *has just been published by Subterranean Press.*

Reviews

Books, artifacts, reports, products, objects

AUTOMOTIVE TECHNOLOGY

Hell and Hydrogen

No matter how well they're engineered, hydrogen cars offer no real answer to the imminent threats posed by global warming.

By David Talbot

By the time Klaus Draeger, BMW's manager of research and development, took the microphone at a Berlin hotel last fall, the assembled journalists' bellies were full of mint juleps—and it all started to make sense. Maybe the world's oil crisis and the threat of climate change could be sensibly addressed by using hydrogen as a transportation fuel. Draeger sketched the alluring vision of a future in which high-performance luxury cars burn hydrogen and emit mostly water vapor. The hydrogen could someday be provided by renewable sources of energy, he said, and nobody would have to make any sacrifices. And we journalists would get to drive the first such cars the following day.

"You'll be pioneers! You will be sitting at the wheel of the Hydrogen 7, driving through Berlin and the countryside. And for the first time, you will drive this hydrogen-powered luxury saloon," Draeger exclaimed, using the Britishism for "sedan." BMW will lend 100 of these cars to yet-unnamed public figures as part of its global clean-energy promotional campaign. In some ways, the campaign resembles GM's effort to tout its own hydrogen-car program. GM's focus is on a futuristic fuel-cell car. The BMW version uses internal combustion: it burns hydrogen rather than skimming off its electrons. Same message, though: hydrogen is the answer.

"Experts will tell you that hydrogen has the biggest possibility to replace fossil fuels," Draeger explained, as the wine flowed. "Please see the Hydrogen 7 as an offer. We can only make this car a reality with our partners in political science, the world of business, the energy industry." He concluded with an appeal to "politicians the world over" to make the production, delivery, and storage of clean hydrogen affordable.

HYDROGEN 7
BMW

HELL AND HIGH WATER: GLOBAL WARMING—THE SOLUTION AND THE POLITICS—AND WHAT WE SHOULD DO
By Joseph J. Romm
William Morrow, 2007, $24.95

The next day, I got a look at the Hydrogen 7. From the outside it looked like a normal BMW four-door luxury sedan. I opened the trunk and marveled at the heavy steel tank that held liquid hydrogen at –253 °C. While driving, I touched a button on the steering wheel to switch from gasoline to hydrogen; I noted no hiccup, just a higher-pitched engine noise. The car is very nice. But does it make environmental sense?

The simple answer is no. In the context of the overall energy economy, a car like the Hydrogen 7 would probably produce far more carbon dioxide emissions than gasoline-powered cars available today. And changing this calculation would take multiple breakthroughs—which study after study has predicted will take decades, if they arrive at all. In fact, the Hydrogen 7 and its hydrogen-fuel-cell cousins are, in many ways, simply flashy distractions produced by automakers who should be taking stronger immediate action to reduce the greenhouse-gas emissions of their cars. As of 2003, transportation emissions accounted for one-third of all U.S. carbon dioxide emissions.

Nobody has made this point more clearly than Joseph Romm does in *Hell and High Water*. Romm is an MIT-trained physicist who managed energy-efficiency programs in the U.S. Department of Energy during President Clinton's administration and now runs a consultancy called the Center for Energy and Climate Solutions. His book provides an accurate summary of what is known about global warming and climate change, a sensible agenda for technology and policy, and a primer on how political disinformation has undermined climate science. In his view, the rhetoric of "technology breakthroughs"—including the emphasis by President Bush and some in the auto industry on a future hydrogen economy—provides little more than official cover for near-term inaction.

Romm reminds us of the growing scientific consensus: we must quickly reduce greenhouse-gas emissions to avoid the worst effects of global warming. Therefore, Romm argues, the job of political leaders is clear. Among other things, they must rapidly adopt tighter

BMW'S Hydrogen 7 sedan burns hydrogen or gas in an internal-combustion engine; liquid hydrogen is stored in a heavy trunk-mounted tank.

COURTESY OF BMW

efficiency standards for homes, offices, and industry; mandate strict increases in automobile fuel economy, which means widespread adoption of ultra-efficient cars, including hybrids; and build as many wind and solar plants as possible, while cautiously expanding nuclear power. Romm even argues that we could cut nationwide carbon dioxide emissions by two-thirds without increasing anyone's annual electric bill. He cites California's three-decade record of aggressive investment in cleaner energy technologies and energy-efficiency programs. When these investments are amortized, costs stay flat while power consumption and carbon dioxide emissions plunge. Today, Romm writes, a Californian has an electric bill no larger than the average American's but generates just one-third the carbon dioxide.

The reason hydrogen-powered cars would produce more carbon dioxide emissions than regular cars starts with the fact that it takes energy to create hydrogen. One way to produce hydrogen is to extract it directly from fossil fuels; indeed, a 2004 National Academy of Sciences study predicted that fossil fuels would be the main source of hydrogen for "several decades." The other way is to split water molecules using electricity. Naturally, BMW talks up this approach, envisioning electricity that would ultimately be supplied by renewable sources. BMW brochures feature the Hydrogen 7 parked in front of wind turbines and shiny photovoltaic arrays. But renewable sources furnish only 2 percent of the world's electricity (not counting hydropower's 16 percent). Coal, by contrast, supplies 39 percent—and is the worst emitter of carbon dioxide, watt for watt. Clearly, a great use for renewable power is to replace coal power. But is it worthwhile to divert even a small part of it to the task of manufacturing hydrogen?

According to Romm's analysis, the math for hydrogen cars simply doesn't work out. Burning coal to generate one megawatt-hour of electricity produces about 2,100 pounds of carbon dioxide. It follows that one megawatt-hour of renewable power can avert those emissions. Using that electricity to make hydrogen would yield enough fuel for a fuel-cell car to travel about 1,000 miles, Romm says. But driving those 1,000 miles in a gasoline-powered car that gets 40 miles per gallon would produce just 485 pounds of carbon dioxide. In this sense, Romm says, a vehicle powered by hydrogen fuel cells would indirectly create four times the carbon dioxide emissions of today's most efficient gasoline cars.

And the numbers for the Hydrogen 7 are worse, because it *burns* hydrogen. Combustion produces thrilling torque, but it's far less efficient than fuel-cell technology. Also counting against the Hydrogen 7 is the fact that it stores hydrogen as a liquid; chilling hydrogen and compressing it into liquid form consumes more energy than storing it as a compressed gas. "It's safe to say this is a pointless activity," Romm says. "BMW has managed to develop the least efficient conceivable vehicle that you could invent."

BMW's new car is a marvelous piece of engineering. But it is also a distraction from the real issues: we must burn less fossil fuel and reduce our greenhouse-gas emissions today. Innovative automakers like BMW should turn their remarkable skills to making cars that are more efficient—such as BMW's new 118d economy hatchback, which on average gets 50 miles to the gallon. But the Hydrogen 7 is hardly the "new standard of sustainable pollutant-free mobility" that BMW proclaims. Draeger's offer is one we would be wise to refuse. TR

David Talbot is Technology Review*'s chief correspondent.*

NANOTECHNOLOGY

Nanocosmetics: Buyer Beware

Is that expensive jar of skin cream on my dresser safe to use?

By Apoorva Mandavilli

There's a lovely jar of night cream that's been sitting on my dresser for a month. According to the salesperson who spent a half-hour on the phone with me extolling its virtues, the cream will dig up the gunk that's clogging my pores, soak up excess oil, and "teach" my cells to make less of it.

Sounds fantastic, doesn't it? Too bad I'm too scared to use it.

The cream, which cost me $163 for half an ounce, is made by New York City–based Bionova. The company's website makes much of its "nano tech platform," and explanations of its products feature incomprehensible phrases such as "restoration of the malfunctioning biological information transfer." But details in plain English of how any of this would actually work are sketchy. And the saleswoman's explanation was similarly cryptic. The cream, she informed me, has various "nano complexes" in an exact ratio that is customized for my age, my gender, and my face's precise degree of oiliness—information gleaned from a number of probing questions she asked me.

BIONOVA
N1-CUSTOM CARE
$163 for .5 oz.
(price varies depending on customized formulation)
www.ibionova.com

How, I asked, did I know these tiny particles weren't going to creep under my skin and wreak havoc with my body? No, she assured me, the cream uses chemicals of a regular size, just in nano amounts. "See the difference?"

Not really. Scientists have for decades been doing experiments using chemicals in nanomolar quantities, which simply means that they're extraordinarily dilute. So how was Bionova's product special? Alexander Sepper, Bionova's vice president for research and development, at first echoed the sales rep's statements. "Our nanotech slightly differs from the nanotech that's made by most companies," he said. "We are not talking about nanoparticles but about nano quantities."

I still didn't understand how the product could be called nanotech if it didn't actually use nano-sized particles. Sepper seemed to agree.

"You know, I should be honest with you. In the beginning, we called them simply biocomplexes," he said. "When nanotech came and everyone started to claim nanotech, nanotech, nanotech, of course the marketing people came to us and demanded that we have to accommodate the present situation. My understanding as a scientist is it's more marketing than science." According to Sepper, revenues from the product, which is sold in upscale stores such as Barneys, went up when Bionova began calling it nanotech. But when I pushed him a bit on the use of the word in marketing the cream, he quickly backtracked. "When I said we are using nano quantities, I thought you already knew that we are using nanoparticles. We are using nano quantities of the nanoparticles."

Confused yet? So was I. And so, it seems, is nearly everyone involved in the marketing of nanotech-based products. The fact is, Bionova is not an exception. Cosmetics are among the first consumer products to make use of nanotechnology—or at least to tout its benefits—but nobody, it appears, has a handle on exactly what is in these products, or how those mystery ingredients might affect people's health.

"You've got this situation where people are putting chemicals on the skin when we know very little about [nanotechnology's] safety," says Sally Tinkle of the North Carolina–based National Institute of Environmental Health Sciences, a division of the National Institutes of Health.

Check the Label

According to the Project on Emerging Nanotechnologies, which is run by the Woodrow Wilson International Center for Scholars in Washington, DC, nearly 400 products on the market claim to use nanotechnology, and 64 of those are cosmetics. And yet no one in the federal government is responsible for overseeing the safety of nanotechnology. "People are miniaturizing the particles, nanosizing them," says Andrew Maynard, science advisor for the Woodrow Wilson project, but he says that companies don't necessarily recognize the risks associated with the unique properties of nanoparticles.

That nanoparticles have unique properties is, of course, exactly the point of using them. When particles of some materials become extremely small, they can exhibit unusual—and interesting—physical and chemical characteristics. Gold nanoparticles, for example, are red and are much more reactive than larger chunks of the metal. Nanoparticle versions of some ingredients used in cosmetics are more stable, improve product texture, and are absorbed better.

Titanium dioxide and zinc oxide, which have been used for decades in sunscreens, are two examples of substances that benefit from nanotechnology. Normally, each material forms a thick whitish coating, but nanosizing their particles makes them translucent—and, naturally, more popular among consumers. Some cosmetics companies use other nanoparticles, such as the 60-carbon soccer-ball-shaped molecules known as fullerenes or buckyballs. Zelens, a company based in London, England, claims that fullerenes in its skin cream help to suck up free radicals and slow aging.

But here's the rub: though some nanomaterials clearly have advantages, such materials might also pose risks. Will the smaller particles penetrate the skin? Can they clog airways and trigger immune responses? Will they lodge in the body's tissues, including the brain?

The simple answer is that no one knows. The U.S. Food and Drug Administration, the Environmental Protection Agency, and other federal agencies have research programs in place that may eventually answer some questions about the toxicity and environmental impact of nanoparticles. But such research will take time and a great deal more money. Through the federal government's National Nanotechnology Initiative, the United States has spent an estimated $6.5 billion on various types of nanotechnology research, but only 4 percent of last year's budget went to assessing potential risks. In the meantime, the best the FDA can do is to say it has "no evidence at present to suggest that any of the materials currently in use pose a major safety concern."

Nano Mysteries

Unlike pharmaceuticals, cosmetics don't have to pass safety tests before they are sold. Cosmetics companies are free to sell their products without such testing—at least until a problem crops up. And so far, nanoparticles used in cosmetics seem to have a clean record.

John Bailey, executive vice president for science at the Cosmetic, Toiletry, and Fragrance Association, an industry trade group in Washington, DC, points out that sunscreens using titanium dioxide and zinc oxide nanoparticles have been used "safely and effectively by consumers for decades" and have been reviewed and approved by the FDA. But whether that record of safety can be extrapolated to other nanoparticles in other types of cosmetics is less certain. The danger is that conventional safety tests for cosmetics and other products might not pick up the special risks nanoparticles pose.

For example, NIH's Sally Tinkle has found that under certain conditions—if the skin is stretched a certain way or rubbed with enough force—nanoparticles can move below its top, dead layer. If the skin has cuts and abrasions or has been damaged in some other way, particles can get through to the layers underneath. "That's well established," says Tinkle. What happens once these particles reach the bloodstream is unclear. Some studies have found that smaller particles are cleared faster than larger ones and so are safer, but others sug-

JULIETTE BORDA

gest that once inside the body, nanoparticles travel through the blood, lodge in the lungs and brain, and accumulate over time, with effects that are still poorly understood.

Definitive answers to these toxicity questions may take some time to emerge. But given that nanoparticles behave differently from their larger counterparts, it makes sense to have a regulatory system that is able to recognize this size-dependent behavior. And it makes sense to provide regulatory oversight based on the unique chemistry of nanoparticles.

That kind of oversight might not be welcomed by the cosmetics industry, but without it, the entire promising field of nanotechnology could be in danger. If a safety problem is associated with a cosmetic product marketed for its nano ingredients (even if it doesn't really have any), the public perception of nanotech could be affected more generally. In Germany, there's already been one scare with a spurious nano product. In March 2006, after the "Magic Nano" spray bathroom cleaner was released, a number of people who had used it fell ill. Amid the confusion that followed, nobody, including the manufacturers, seemed to know exactly what was in the product. But the damage to nanotech's reputation had been done. "What it really highlights is the confusion about what people actually mean by the terms," says Maynard. "We need transparency in this whole area."

In Bionova's case, I'm still not sure whether the cream on my dresser contains any nanoparticles, and if it does, whether they will help or hurt me. Since the small dark-blue jar arrived, salespeople from the company have called me four times—ostensibly to check on whether I have any questions. During the first call, the sales rep told me that for the first few days of use, when the cream is opening up my pores and cleaning them out, "your skin is going to look aggravated. It's going to look itchy; it's going to look flaky."

I've yet to do more than smell the cream, and I doubt I ever will, so I won't know whether glowing skin would follow the flakiness, as the salesperson assured me. No matter how lovely the jar is or what lofty promises are made on behalf of its contents, the specter of tiny little nano-whatevers making their way through my body is enough to keep me away. TR

Apoorva Mandavilli is senior news editor at Nature Medicine.

GENETIC TESTING

Choosing Babies

A growing number of genetic tests can be performed during in vitro fertilization, before pregnancy even begins. Is that a good thing?

By Emily Singer

A 38-year-old woman with fertility problems has three sons but wants a daughter to round out the family. She uses in vitro fertilization (IVF) to conceive and asks her doctors to transfer only female embryos; the male embryos are destroyed. Is this use of reproductive technology acceptable? What if a couple with a family history of diabetes wants to use IVF to select an embryo without a particular gene linked to diabetes risk? If afflicted family members largely have the disease under control, are the prospective parents justified in choosing in vitro fertilization so that they can bear a child with a lower chance of developing it at all?

GENETIC TESTING OF EMBRYOS: PRACTICES AND PERSPECTIVES OF U.S. IVF CLINICS
Susannah Baruch et al.
Fertility and Sterility, September 2006

Such questions are becoming more common as preimplantation genetic diagnosis (PGD)—testing performed after an egg is fertilized in vitro but before the resulting embryo is transferred to the womb—makes it possible for some prospective parents to select specific embryos before a pregnancy begins. Originally developed more than a decade ago to identify the relatively small number of embryos at high risk for serious or fatal genetic diseases, such as Tay-Sachs, the technology now encompasses genetic tests for a growing number of illnesses, including some that are not necessarily fatal. And these tests are available to more and more parents as the popularity of in vitro fertilization skyrockets; approximately 50,000 babies are born through IVF in the United States every year.

All this heightens the ethical concerns that have plagued PGD from the start. As more genes associated with the likelihood of disease are uncovered, the possibility of a truly preventive medicine is within the grasp of many parents. But with that possibility come risks. How well will any one test deliver on its promise of a healthy child? Will parents feel obligated to use genetic testing without adequately understanding its benefits? What kinds of genetic tests will parents want? Recent findings suggest that an increasing number of parents using IVF are choosing embryos according to sex, and it's possible to imagine them one day choosing embryos based on other nonmedical traits, such as hair color, height, or IQ.

Preimplantation genetic testing is available only to those who opt for IVF—which now generally means people with fertility problems or a family history of a fatal genetic illness. Though IVF is gaining in popularity, it remains an expensive and often difficult procedure. But the grounds for choosing it are changing: some people, for example, are now using it to select embryos without genes linked to particular cancers—even if the correlation is fairly weak. If parents increasingly choose IVF because it will offer them the opportunity to tailor their children's genetic traits, will the economic division of society become even deeper—separating those who can afford IVF (clinics in the United States generally charge between $6,000 and $16,000) from those who cannot?

"This is a potentially disruptive technology, one that can change the social structure and order," says David Adamson, president-elect of the American Society for Reproductive Medicine and director of a private fertility clinic in northern California. "It will move us toward a preventive approach to medicine and could change our approach to reproduction."

Tests are already available for genetic variants associated with a thousand conditions, including deadly childhood illnesses and adult-onset cancers, and more genes associated with disease risk are being discovered every day. Any such gene could be a target of PGD. Santiago Munné, director of Reprogenetics, a genetics laboratory headquartered in Livingston, NJ, says his lab has tested embryos for more than 150 diseases or risk genes—most recently for a gene variant known as BRCA1, which raises the risk of breast cancer.

Little data yet exists on the use of preimplantation genetic tests. But late last year, the Genetics and Public Policy Center at Johns Hopkins University released a report in the journal *Fertility and Sterility* presenting some of the first statistics on the use of PGD nationwide. "We wanted to get a sense of how much PGD was being done, and why," says Susannah Baruch, the center's director of reproductive genetics and lead author of the report. "Without solid data, it's difficult to analyze outcomes for PGD babies or to help prospective parents make decisions about whether to pursue PGD."

The researchers surveyed all the fertility clinics in the United States that offer IVF, asking questions about the types of preimplantation tests they administer, how they make ethical decisions, and how they think testing should be regulated. About half of those clinics responded. According to the survey, screening for chromosomal abnormalities that can lead to implantation failure or miscarriage, or for disorders linked to chromosome duplication or deletion (such as Down's syndrome), represents two-

BLUESTONE/ PHOTO RESEARCHERS, INC

thirds of all PGD testing. Tests for genetic diseases such as cystic fibrosis account for another 12 percent. Forty-three percent of clinics said they had received requests for PGD that they felt raised ethical questions; most of these were from parents who wanted to select the sex of a child for nonmedical reasons. The survey found that this use of PGD is fairly common: almost one in ten tests was for nonmedical sex selection, a service offered by 42 percent of clinics.

Since it is the only PGD test that is often administered without medical justification, sex selection is especially contentious; some fertility clinics will not offer it, and some ethicists say that nonmedical sex selection opens the door to other types of nonmedical testing. But other people argue that biological enhancement through genetic screening is not so alarming, or at least not so different from other types of advantages that are already enjoyed by a certain privileged sector of the population. "I don't think testing for freckles or blond hair or musical aptitude is a morally bad thing to do," says Arthur Caplan, director of the Center for Bioethics at the University of Pennsylvania. "I think parents will want to do it, so I think this will expand rapidly."

Testing for medical purposes brings its own set of problems. Only a limited number of genetic variations present the kind of clear-cut case for which PGD was originally developed: the certainty of a serious or fatal disease. But what about testing for genes that merely raise the risk of a disease? Or for genes linked to a relatively manageable disease, such as diabetes? How serious must a disease be to justify the costly and potentially risky process of IVF?

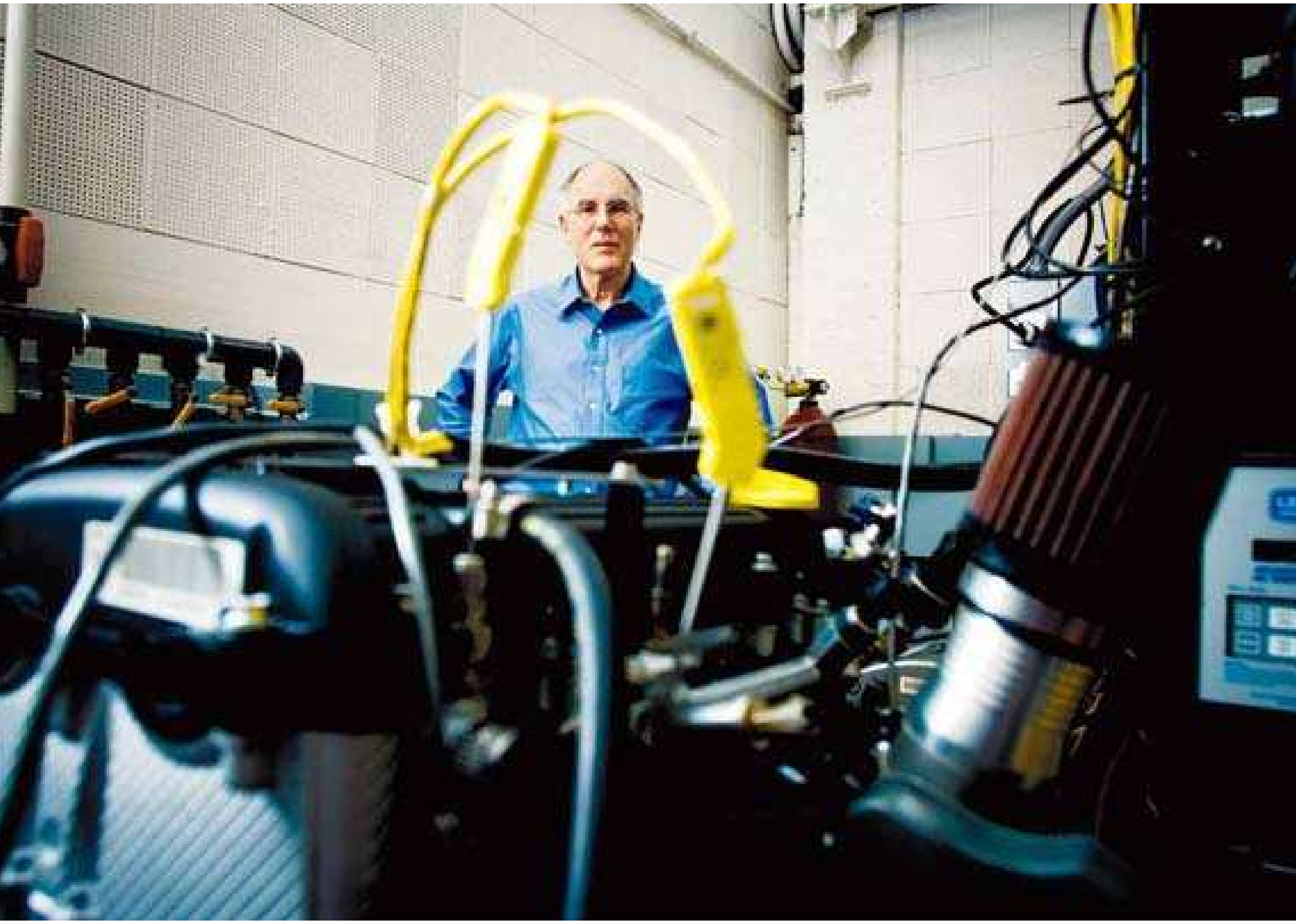
"That is a major debate in the profession," says George Annas, chair of the department of health law, bioethics, and human rights at the Boston University School of Public Health. Another problem is that parents may eventually find themselves with more information than they or their doctors know how to use. As more disease-linked gene variants are discovered—and the list is rapidly growing—parents will face so many choices that it will be difficult, if not impossible, to determine which genetic combination will produce the healthiest child.

In the United Kingdom, a government body licenses fertility labs and regulates which tests can be administered. But the United States has fewer rules; it is one of the few countries, for example, that permit nonmedical sex selection. "Today, in this country, the clinics are the gatekeepers," says Vardit Ravitsky, a bioethicist at the University of Pennsylvania. "If you have cash and can find a clinic to provide the service, you can get it, whether it's a test for Huntington's disease or sex selection."

So decisions regarding PGD are left in the hands of doctors or clinics. Professional societies provide some ethical guidelines—the American Society for Reproductive Medicine, for example, recommends against sex selection for nonmedical reasons, though it has little to say about other aspects of PGD. But voluntary guidelines regulating a profit-driven industry may not be enough to help prospective parents. "I think there will be people hyping the advantages of this, which will be just like pharmaceutical advertising today," says Caplan. "I think people will be guilted into doing this, rather than choosing it." They may also be "guilted" into testing that doesn't make good on the promise of a healthier child; most of the newly discovered genes have relatively weak correlations with disease or play small roles in complicated processes, and some may affect the body in ways that scientists don't yet fully understand.

Some kind of regulation for preimplantation genetic testing is needed, but the rules must focus not on limiting which tests a parent can choose but on making sure that clinics can scientifically justify the claims made for each test. Then parents and their doctors can begin to make informed choices. "I definitely think the government has a role to play in regulating the safety and quality of tests and in the application of tests," says Adamson. "But the final choice, once tests are considered to be scientifically legitimate, should be left up to patients and physicians." TR

Emily Singer is the biotechnology and life sciences editor of Technology Review.



The Incredible Shrinking Engine

A new engine design could significantly improve fuel efficiency for cars and SUVs, at a fraction of the cost of today's hybrid technology.

By Kevin Bullis

For Daniel Cohn, a senior research scientist at MIT's Plasma Science and Fusion Center, the century-old internal-combustion engine is still a source of inspiration. As he strides past the machinery and test equipment in the MIT Sloan Automotive Laboratory, his usually reserved demeanor drops away. "An engine this size," he says, pointing out an ordinary-looking 2.4-liter midsize gasoline engine, "would be a rocket with our technology."

By way of explaining that technology, he shows off a turbocharger that could be bolted to the 2.4-liter engine; the engine, he adds, uses direct fuel injection rather than the port injection currently found in most cars. Both turbocharging and direct injection are preëxisting technologies, and neither looks particularly impressive. Indeed, used separately, they would lead to only marginal improvements in the performance of an internal-combustion engine. But by combining them, and augmenting them with a novel way to use a small amount of ethanol, Cohn and his colleagues have created a design that they believe could triple the power of a test engine, an advance that could allow automakers to convert small engines designed for economy cars into muscular engines with more than enough power for SUVs or sports cars. By extracting better performance from smaller, more efficient engines, the technology could lead to vehicles whose fuel economy rivals that of hybrids, which use both an electric motor and a gasoline engine. And that fuel efficiency could come at a fraction of the cost.

Cohn says that his colleagues—Leslie Bromberg, a principal research

PHOTOGRAPHS BY PORTER GIFFORD

At MIT's Sloan Automotive Laboratory, Daniel Cohn (opposite page) stands behind an engine equipped with test instruments (in yellow) and an injection system that sprays fuel directly into the engine's combustion chambers. A conventional gasoline engine augmented with direct injection of ethanol (which is mixed with 15 percent gasoline in the can shown above) is able to generate far more power. That's in part because it's capable of extreme turbocharging. A turbocharger, with turbine blades visible, is pictured at left.

scientist at the Plasma Science and Fusion Center, and John Heywood, a professor of mechanical engineering and director of the Sloan Auto Lab—considered many ways to make internal-combustion engines more efficient. "And then, after a lot of discussion, it just sort of hit us one day," Cohn recalls. The key to the MIT researchers' system, he explains, was overcoming a problem called "knock," which has severely limited efforts to increase engine torque and power.

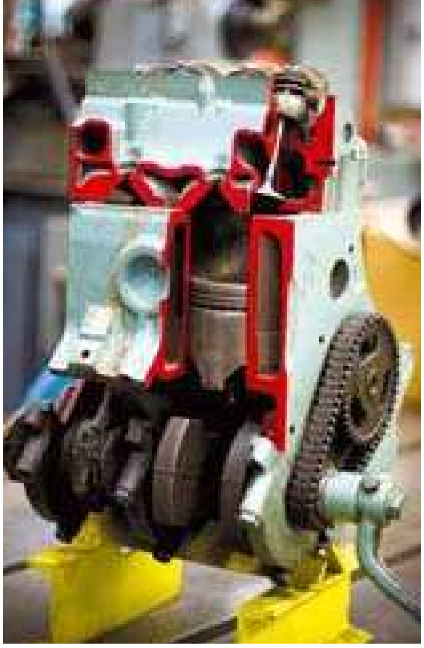
In gas engines, a piston moves into a cylinder, compressing a mixture of air and fuel that is then ignited by a spark. The explosion forces the piston out again. One way to get more power out of an engine is to design the piston to travel farther with each stroke. The farther it travels, the more it compresses the air-fuel mixture, and the more mechanical energy it harvests from the explosion as it retreats. Overall, higher compression will lead to a more efficient engine and more power per stroke. But increasing the pressure too much causes the fuel to heat up and explode independently of the spark, leading to poorly timed ignition. That's knock, and it can damage the engine.

To avoid knock, engine designers must limit the extent to which the piston compresses the fuel and air in the cylinder. They also have to limit the use of turbocharging, in which an exhaust-driven turbine compresses the air before it enters the combustion chamber, increasing the amount of oxygen in the chamber so that more fuel can be burned per stroke. Turning on a car's turbocharger will provide an added boost when the car is accelerating or climbing hills. But too much turbocharging, like too much compression, leads to knock.

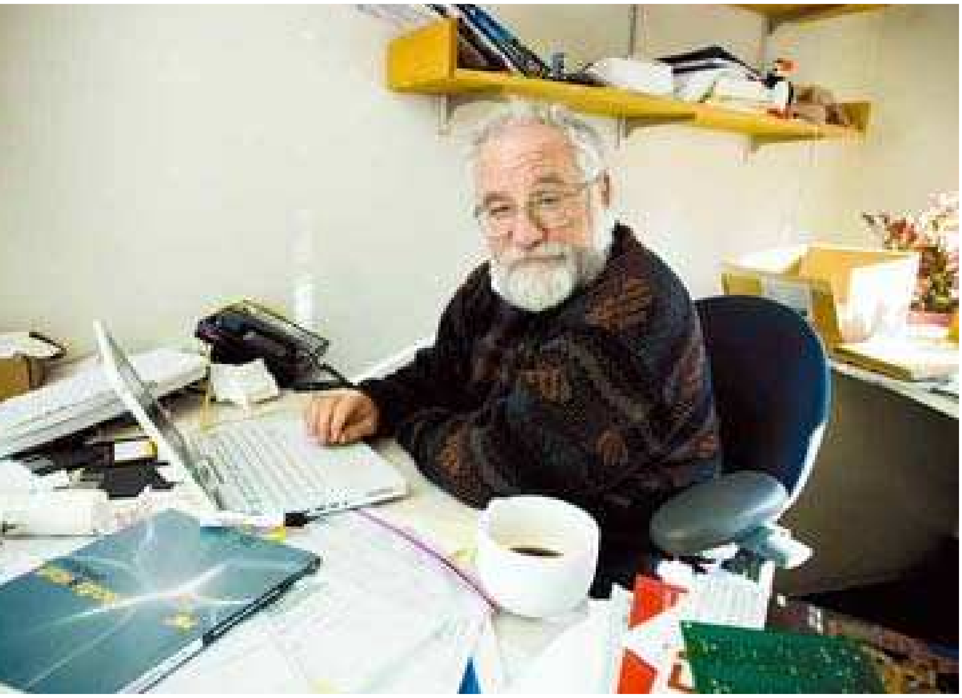
An alternative way to prevent knock is to use a fuel other than gasoline; although gasoline packs a large amount of energy into a small volume, other fuels, such as ethanol, resist knock

far better. But a vehicle using ethanol gets fewer miles per gallon than one using gasoline, because its fuel has a lower energy density. Cohn and his colleagues say they've found a way to use both fuels that takes advantage of each one's strengths while avoiding its weaknesses.

The MIT researchers focused on a key property of ethanol: when it vaporizes, it has a pronounced cooling effect, much like rubbing alcohol evaporating from skin. Increased turbocharging and



A cutaway view of a gasoline engine (left) at the Sloan Auto Lab reveals a combustion chamber (center of photo), into which a piston has partially advanced. In a new system, which Leslie Bromberg (below) modeled on a computer, direct injectors would spray a fine mist of ethanol into the chamber, where it would instantly vaporize before the fuel mixture is compressed by the piston and ignited by a spark plug.



cylinder compression raise the temperature in the cylinder, which is why they lead to knock. But Cohn and his colleagues found that if ethanol is introduced into the combustion chamber at just the right moment through the relatively new technology of direct injection, it keeps the temperature down, preventing spontaneous combustion. Similar approaches, some of which used water to cool the cylinder, had been tried before. But the combination of direct injection and ethanol, Cohn says, had much more dramatic results.

The researchers devised a system in which gasoline would be injected into the combustion chamber by conventional means. Ethanol would be stored in its own tank or compartment and would be introduced by a separate direct-injection system. The ethanol would have to be replenished only once every few months, roughly as often as the oil is changed. A vehicle that used this approach would operate around 25 percent more efficiently than a vehicle with a conventional engine.

A turbocharger and a direct-injection system would add to the cost of an engine, as would strengthening its walls to allow for a higher level of turbocharging. The added equipment costs, however, would be partially offset by the reduced expense of manufacturing a smaller engine. In total, an engine equipped with the new technology would cost about $1,000 to $1,500 more than a conventional engine. Hybrid systems, which are expensive because they require both an internal-combustion engine and an electric motor powered by batteries, add $3,000 to $5,000 to the cost of a small to midsize vehicle—and even more to the cost of a larger vehicle.

When the MIT group first hatched its idea, Bromberg created a detailed computer model to estimate the effect of using ethanol to enable more turbocharging and cylinder compression. The model showed that the technique could greatly increase the knock-free engine's torque and horsepower. Subsequent tests by Ford have shown results consistent with the MIT computer model's predictions. And since the new system would require relatively minor modifications to existing technologies, it could be ready soon. Ethanol Boosting Systems, a company the researchers have started in Cambridge, MA, is working to commercialize the technology. Cohn says that with an aggressive development program, the design could be in production vehicles as early as 2011.

While Cohn applauds the benefits of hybrids and says his technology could be used to improve them, too, he notes that the popularity of hybrid technology is still limited by its cost. Cheaper technology will be adopted faster, he suggests, and will thus reduce gasoline consumption more rapidly. "It's a lot more useful," he says, "to have an engine that a lot of people will buy." TR

From the Labs

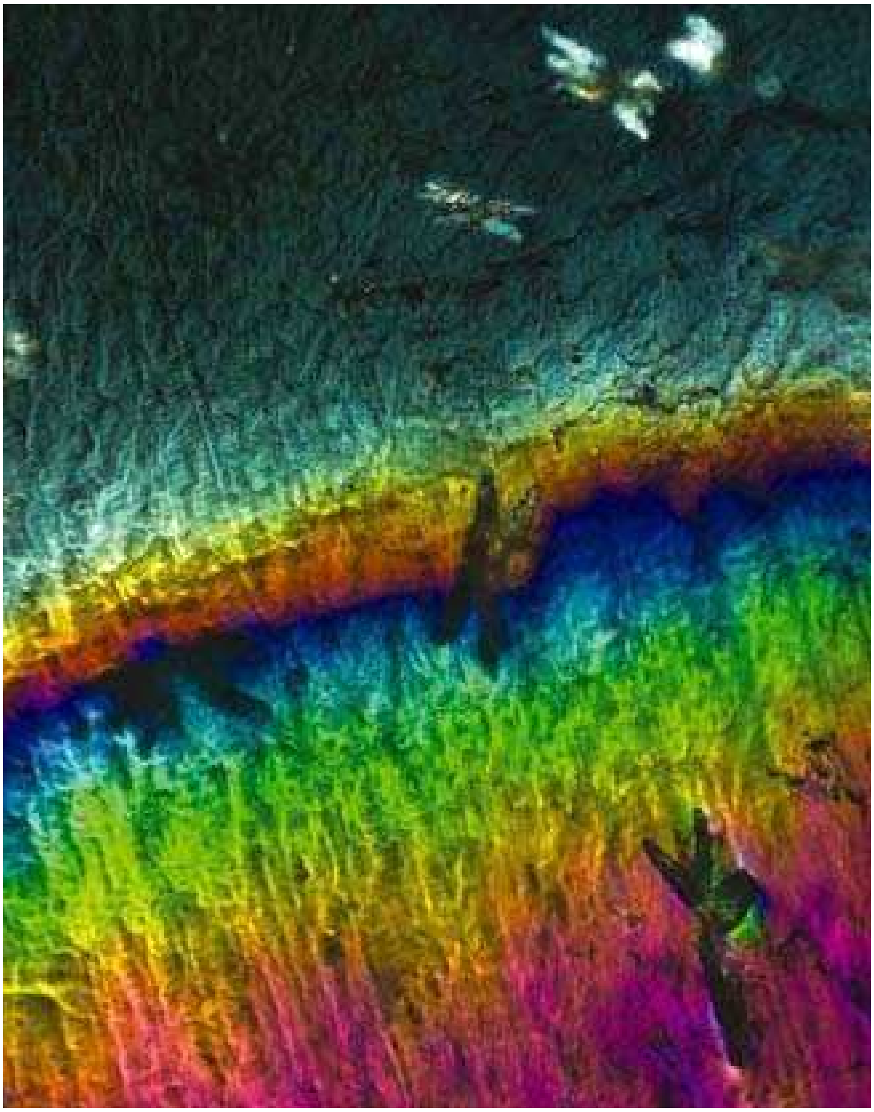
Current research in nanotechnology, biotechnology, and information technology

NANOTECHNOLOGY

Tough Nanomaterials

Potential applications include tear-resistant fabrics and fuel-saving car parts

SOURCE: "High-Performance Elastomeric Nanocomposites via Solvent-Exchange Processing"
Shawna M. Liff et al.
Nature Materials 6: 76–83



Microscopic structures in a new, ultratough material that is reinforced with disc-shaped nanoparticles change shape under stress, altering the way they refract light.

RESULTS: Researchers have found that using clay nanoparticles to reinforce a polyurethane material makes it 20 times as stiff and twice as resistant to heat. The polyurethane is composed of two different types of monomers—molecules linked up into polymer chains. The monomers don't mix well, so they locally separate into hard organized regions and soft amorphous regions. A new dispersion process ensures that the nanoparticles preferentially reinforce the hard regions, making the polyurethane stiffer. Since the process also leaves the soft, amorphous areas free to flex, the material can still stretch substantially without breaking.

WHY IT MATTERS: To date, most attempts to use nanoparticles to stiffen elastomers such as polyurethane have also resulted in undesired decreases in flexibility, which can mean increases in brittleness. The new process not only makes the material stiffer but also makes it much tougher. The material could be used in lightweight, resilient packaging or spun into fibers to make tear-resistant clothing. Or, in an application that takes advantage of its heat resistance, it could replace some metal car body parts exposed to elevated temperatures, such as the hood. The general processing method could also be used to make a wide range of other new elastic materials.

METHODS: The process uses two solvents. In one, the clay nanoparticles are dispersed; the other dissolves the polyurethane. The two solvents are then mixed until the suspended nanoparticles spread evenly throughout the dissolved polymer. When the second of the solvents is removed or evaporates, the clay particles are trapped within a tangle of polymer chains. The clay nanoparticles are selected to have a chemical affinity for the crystalline

MCKINLEY LAB

hard structures within the polyurethane, so those are what they preferentially aggregate with, rather than with the soft, amorphous regions.

NEXT STEPS: Reducing the amount of solvent used could make the manufacturing process cleaner and easier. Making actual products from the material may require adjusting manufacturing techniques: too much heat during processing may reduce the material's stiffness.

Practical Nanosensors

An easier way to make nanowire sensors and integrate them into electronics could lead to handheld detectors of pathogens, cancer

SOURCE: "Label-Free Immunodetection with CMOS-Compatible Semiconducting Nanowires"
Eric Stern et al.
Nature 445: 519–522

RESULTS: Researchers at Yale University have found an easier way to manufacture nanowire sensors, and their process is compatible with those used to make computer chips. The sensors can detect small concentrations of proteins about as reliably as previous nanowire sensors could.

WHY IT MATTERS: Today, detecting biological molecules in ultrasmall concentrations requires tagging them with fluorescent dyes and viewing them through bulky optical readers. Nanowire sensors generate electronic signals rather than optical ones, and they do not require tagging, so they can be much smaller and easier to use. As a result, they could lead to handheld sensors that can screen for faint traces of hundreds of pathogens or for early signs of cancer. The new technique could also make it much easier to integrate nanosensors and the electronics that process their signals on individual chips. Such sensors would be more practical to mass-produce.

METHODS: The researchers first created patterns on silicon using conventional lithography; chemical etching then removed the nonpatterned silicon, leaving behind silicon wires. But because the wires were still too thick, the researchers let the etching agent continue to eat away at the material under the edges of the pattern.

NEXT STEPS: The researchers are demonstrating the sensors' ability to detect different molecules, such as virus particles, DNA, and a wider range of proteins.

BIOTECHNOLOGY

Stem Cells from Amniotic Fluid

Cells collected during pregnancy could aid research and therapy

SOURCE: "Isolation of Amniotic Stem Cell Lines with Potential for Therapy"
Paolo De Coppi et al.
Nature Biotechnology 25(1): 100–106

RESULTS: Scientists have isolated stem cells from amniotic fluid and found that they appear to have properties similar to those of embryonic stem cells. The cells grew efficiently in the lab, doubling in number every 36 hours, and were able to develop into precursors of multiple tissue types, including brain tissue.

WHY IT MATTERS: Unlike embryonic stem cells, cells routinely discarded during amniocentesis could be harvested without destroying human embryos, avoiding the ethical concerns that have slowed stem cell research. And unlike most adult stem cells, those derived from amniotic fluid appear to grow efficiently and can differentiate into multiple cell types, making them suitable for therapeutic and research uses.

METHODS: The researchers, led by Anthony Atala at Wake Forest, collected samples of amniotic fluid and isolated cells that expressed a molecule unique to stem cells. They then grew the cells under different environmental and chemical conditions to trigger their differentiation into different cell types.

Researchers at Wake Forest have isolated cells from amniotic fluid and, after multiplying the cells in the lab, are able to coax them into becoming a particular cell type.

WAKE FOREST UNIVERSITY SCHOOL OF MEDICINE

NEXT STEPS: The researchers plan to try to develop the cells for use in treating diseases. They'll try to make nerves for Parkinson's patients, for instance, or insulin-secreting cells for people with diabetes.

Longevity Gene Keeps Brain Agile

People with a cholesterol-gene variant are more likely to live longer, with better brain function

SOURCE: "A Genotype of Exceptional Longevity Is Associated with Preservation of Cognitive Function"
Nir Barzilai et al.
Neurology 67(12): 2170–2175

RESULTS: A specific version of a gene involved in cholesterol transport may also help keep the mind sharp in old age. In a group of 158 Ashkenazi Jews aged 95 and older, those with the gene variant, which has previously been linked to longevity, were twice as likely to pass tests of mental agility as those with a different version of the gene. Among 124 people, aged 75 to 85, from an unrelated Ashkenazi population, those individuals with the gene variant were five times as likely to be free of dementia and perform well in memory tests.

WHY IT MATTERS: Scientists would like to create drugs that can mimic the effects of age-defying genes. But first, they must identify the genetic variations that allow some people to stay physically and mentally healthier in old age. In a previous study of Ashkenazi Jews, Nir Barzilai and colleagues found that this gene variant is seen three times as often in centenarians as in others. People with the variant also seem to have larger cholesterol particles in their blood, providing a hint at the gene's mechanism. Now the researchers have linked the gene to preservation of mental function. Taken together, the findings point to a potential target for drugs that could protect against dementia and otherwise delay the aging process.

METHODS: Barzilai and his colleague Gil Atzmonran tested people of Ashkenazi Jewish descent who were 95 or older and confirmed the results in a group of 75- to 85-year-olds of the same descent. Medical geneticists often study groups, such as the Ashkenazi, descended from a relatively small number of ancestors because they're more genetically homogenous, making it easier to identify genetic associations.

NEXT STEPS: Scientists are now examining the frequency of the gene variant in people with Alzheimer's. They also plan to study how expression of the protein produced by the gene affects the brain in animals.

INFORMATION TECHNOLOGY

More-Realistic Fluid Animations

A new approach helps computer-animated fluids flow more naturally

SOURCE: "Stable, Circulation-Preserving, Simplicial Fluids"
Mathieu Desbrun et al.
ACM Transactions on Graphics 26(1)

RESULTS: Researchers at the California Institute of Technology have developed a new geometric approach to simulating fluid flow that's more realistic.

WHY IT MATTERS: Numerical approaches commonly used in computer animation and in aerodynamics simulations contain inaccuracies that can cause graphically depicted liquids to appear to flow unnaturally. For instance, when used to model whirlpools, these equations predict an exaggerated decrease in energy, so animations of swirling water slow down for no apparent reason. Animators need to spend time correcting these errors by hand. A numerical treatment that better respects liquids' actual behavior could save animation studios time and money.

The spinning liquid in this snow globe is the product of a new animation technique developed at Caltech. The researchers say their geometric approach yields more realistic simulations of moving liquid.

MATHIEU DESBRUN, APPLIED GEOMETRY LAB, CALTECH

METHODS: The researchers used a new type of mathematics called discrete differential geometry to calculate the flux of a flowing liquid, a property that determines the velocity and position of the liquid at any time. The researchers say that because their equations use flux, rather than just fluid velocity, they more accurately capture the behavior of swirling liquids.

NEXT STEPS: The new approach should yield simulations that better predict the flow of fluids—say, water or air turbulence around planes or boats. Eventually, the approach could be incorporated into software for movie studios, but that will require more research on how to modify the equations to simulate a wider range of natural phenomena.

Extra Room for Transistors

New architecture could make chips faster and keep Moore's Law alive

SOURCE: "Nano/CMOS Architectures Using a Field-Programmable Nanowire Interconnect"
Gregory S. Snider and R. Stanley Williams
Nanotechnology 18: 035204

RESULTS: Hewlett-Packard Labs researchers R. Stanley Williams and Greg Snider have redesigned the chips known as field-programmable gate arrays to make room for eight times as many transistors, without shrinking the transistors themselves.

WHY IT MATTERS: As electronic devices, such as transistors, grow smaller, engineers can pack them closer together, producing faster and more powerful computer chips. In the next decade, however, the standard techniques for shrinking transistors will run up against fundamental physical limits, so engineers are looking for new ways to increase the density of chip circuitry.

METHODS: In today's chips, some of the silicon real estate is taken up by aluminum-wire interconnects that supply power and instructions to the transistors. To make room for more transistors, the HP researchers designed a chip whose wires are on top of instead of in between the transistors. They used what they called a "crossbar structure," a sort of nanoscale wire mesh developed at HP. Each junction in the mesh acts as a switch that controls the flow of electrons to and from the transistor beneath it.

NEXT STEPS: The researchers are developing a laboratory prototype that uses the design, and Williams expects it to be complete by the end of the year. By 2010, he says, the technology should be ready for manufacturing. TR

34 Years Ago in *TR*

Jump-Starting Solar Energy

The potential of solar energy remains unfulfilled.

By Katherine Bourzac

In October 1973, the Organization of the Petroleum Exporting Countries raised oil prices by 70 percent; by December, it had raised prices an additional 130 percent, and its Arab members embargoed oil shipments to the United States.

The U.S. began to look at alternative sources of energy, like solar, wind, and geothermal. Citing the solar energy available at the rate of 1,400 watts per square meter just outside Earth's atmosphere, an article in the December 1973 *TR* argued in its title, "Solar Energy: Its Time Is Near." The article, by Walter E. Morrow Jr., associate director of MIT Lincoln Laboratory, provided an economic analysis of solar's potential to transform the country's energy landscape.

Morrow recommended that the country spend $300 billion over 27 years researching, developing, and implementing solar-energy systems—from solar-panel-equipped satellites that would use microwaves to beam energy back to Earth, to household water heaters, to fields of solar panels like the one featured in this issue's photo essay *(see "Good Day Sunshine," p. 36)*. The return on an investment of more than $11 billion a year, he argued, would be huge: by 2000, solar could provide 13 percent of the country's energy, by 2020, 26 percent.

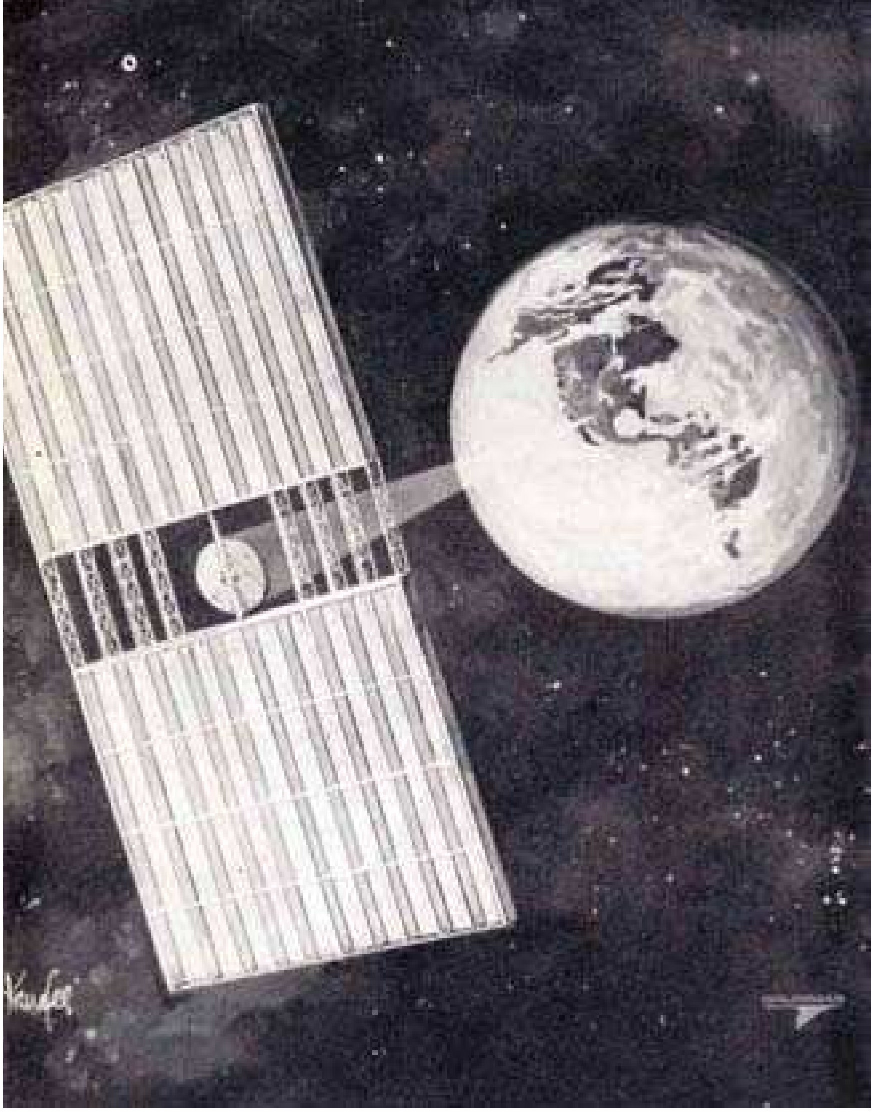
But if these rapid advances are to occur, large capital investments will also be required. … the cost of the various types of solar energy systems can be projected as follows:

Residential solar heaters: $4,000 each
Total-energy plants: $50/m² of building supplied, or $100/m² of collector area
Electric base-load power plants: $700/kw of electrical output power, or $40/m² of collector
Hydrogen production plants: $40/m² of collector

…

Combining the cost of research and development, production facilities, and the systems themselves gives a total solar-energy investment of about $300 billion in the next 27 years. … investment at that level would mean that 13 per cent of projected U.S. energy requirements could be filled by solar systems in the year 2000, 26 per cent in 2020.

While substantial collector areas would be required, the total area involved by the year 2020, about 10^4 km², would be much less than that used currently for highways. In fact, a substantial fraction of the collector area needed could be accommodated on … land shared with farming or grazing.



A design for a satellite solar-power station proposed by the consultancy Arthur D. Little. The satellite would stay in synchronous Earth orbit for a clear view of the Sun; energy from the panels would be beamed to an antenna on Earth via microwaves.

But gas prices fell, and the United States did not spend nearly this much money on solar. In its entire existence, the U.S. Department of Energy has spent $5.8 billion on the technology. In 2004, solar supplied only .0628 percent of the country's energy. And President Bush's 2008 budget calls for only $148 million for solar research.

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